GUNNISON RIVER / ASPINALL UNIT TEMPERATURE STUDY - PHASE I

FINAL REPORT

PREPARED FOR:

UPPER COLORADO RIVER ENDANGERED FISH RECOVERY PROGRAM

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HYDROSPHERE
Resource Consultants

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LIST OF KEY WORDS

Gunnison River, Blue Mesa Reservoir, Morrow Point Reservoir, Crystal Reservoir, Water Temperature, Reservoir Temperature, Temperature Control Device

EXECUTIVE SUMMARY

Introduction

Hydrology of the Gunnison basin has been significantly altered by the construction and operation of the Aspinall Unit (Blue Mesa, Morrow Point and Crystal Reservoirs), numerous other smaller reservoirs, and diversion and return flow features related to irrigation in the basin, particularly in the areas surrounding Montrose and Delta. Cold-water releases from the Aspinall Unit reservoirs have been identified as a significant impediment to re-establishment of pikeminnow habitat in the Gunnison River near Delta (Osmundson, 1999). Results of Osmundson's work indicate that increasing mean water temperatures at Delta by 1 ^{o}C in June, September and October, and by 2 ^{o}C in July and August, would increase the mean annual thermal units (ATU) from 32 to 46 units. Such an increase would put stream temperatures at Delta at a level similar to sites on the Yampa and Colorado Rivers which have abundant populations of pikeminnow.

The objective of this phase I study was to determine the feasibility of increasing stream temperatures in the Gunnison River at and below Delta, Colorado through structural and / or operational modifications to the Aspinall Unit reservoirs. The project is being approached in a two-step process. The first phase of the work, which this report summarizes, includes: data collection and assessment; an overview of factors that may constrain the Program's ability to meet temperature objectives; a cursory analysis of the data with the intent of gaining insight into the primary physical processes governing water temperature in the basin; and modeling recommendations for the second phase of the work.

Phase II of the project, if approved, would involve development of numerical models of both the Aspinall reservoirs and the Gunnison River downstream. The objective of phase II would be to use these models to simulate temperatures in the river / reservoir system under a variety of Temperature Control Device options and flow regimes.

Results and Recommendations

We must stress that the results presented here are based on a preliminary analysis of the available data. We strongly recommend that a rigorous modeling effort be undertaken, with a particular focus on how thermal regimes in the three Aspinall reservoirs could change with installation of a temperature control device (TCD).

The results of phase I of the Gunnison River / Aspinall Unit Temperature Study indicate that Aspinall Unit construction and operation has had a significant impact on water temperatures at Delta, and that warmer release temperatures during the summer would in most cases translate into warmer temperatures in the river near Delta. The findings also indicate that a TCD on Blue Mesa Dam is likely to be the best approach to achieving warmer releases from Crystal Dam. Although modified annual flow patterns have also impacted water temperatures at Delta, complications arising from physical and institutional constraints would severely limit the effectiveness of a flow-based temperature management approach.

Data Collection. An extensive data collection program was completed during the summer of 2001. Much of the data required to conduct model development and calibration during phase II of the project were obtained. These data include meteorological, hydrological, and water temperature time series data, as well as physiographic and engineering data pertaining to reservoirs, dams, and river reaches. Based on a review of the data, no additional field work was conducted during 2001. We did however recommend to George Smith of the FWS that temperature recording devices be placed at least temporarily near the mouths of the Uncompahgre and North Fork of the Gunnison Rivers to provide additional baseline data on tributary inflow temperatures. Additionally, one or more temperature recording devices on the mainstem of the Gunnison and certain major tributaries above Blue Mesa Reservoir (e.g., Lake Fork, Cebolla, Willow, etc.) would be useful for development and calibration of a Blue Mesa temperature model.

Data Analysis. The primary objective of phase I of this project was to determine whether or not modifications to the Aspinall Unit could result in warmer water temperatures downstream near Delta. Before undertaking a substantial model development program, the Recovery Program asked that we undertake a preliminary analysis of the data with the purpose of 1) providing a preliminary analysis of whether or not increased water temperatures are possible with reservoir modifications, and 2) what type(s) of modeling approach is most appropriate given the nature of the Gunnison system. Our scope for phase I was limited to some straightforward processing of data for visualization and preliminary statistical analyses. Nevertheless, the following conclusions can be drawn:

1. Stream temperatures near Delta are significantly impacted by Aspinall operations, and do not return to ambient conditions until somewhere downstream of Delta.

2. Blue Mesa Reservoir is the primary cause of cold-water releases from the Aspinall Unit. Crystal releases are warmer than those of Blue Mesa, indicating that Morrow Point and Crystal actually warm the river relative to Blue Mesa release temperatures.

3. Warmer water is physically available in Blue Mesa, and could be released downstream with a TCD. Models of all three reservoirs would be useful in determining the impacts of such a structure on the thermal regimes of the reservoirs.

4. Tributary inflows do impact stream temperatures at Delta, but not with a frequency or magnitude to render potential reservoir control ineffective.

5. Warmer releases from Crystal would result in warmer river temperatures at Delta. Generally, release temperatures from Crystal would need to be increased about 3 ^{o}C to warm the river at Delta by 2 ^{o}C.

6. Stream temperatures at Delta show a strong statistical correlation to release temperatures and atmospheric conditions; thus, a statistical model could potentially be used in lieu of a more costly physically-based model of the river.

Constraints. We focused this work predominantly on questions of whether or not it would be physically possible to obtain warmer stream temperatures near Delta through operational or structural modifications to the Aspinall Reservoirs. However, a significant consideration of any proposed change to the system would necessarily involve non-physical factors including (but not limited to) lost hydropower revenue, state and federal reserved water rights, interstate and international compacts, minimum instream flows, recreational impacts, and capital costs. A summary of these and other constraints was compiled through numerous conversations with local, state, and federal agency personnel and other parties with an interest in the Recovery Program. A description of the constraints and their potential impacts on the Program's ability to control water temperatures are provided in the report.

Modeling Recommendations. Based on the data analysis, we strongly recommend modeling all 3 Aspinall reservoirs, using QUAL-W2, and a multi-variate statistical model of Gunnison River temperatures. Stratification of Morrow Point and Crystal Reservoirs is complicated by hypolimnetic inflows from Blue Mesa, and a mechanistic model is needed to predict changes in stratification due to a TCD.

Results from these model outputs in phase II would answer several questions, including:

1. Would a TCD at Blue Mesa result in warmer release temperatures at Crystal?
2. If so, how much warmer would they be?
3. Would these warmer release temperatures translate into warmer river temperatures in the area around Delta?
4. What are the benefits of a fixed versus variable height withdrawal structure?
5. How would a TCD impact the thermal structure of the Aspinall reservoirs?

1. INTRODUCTION

Hydrology of the Gunnison basin has been significantly altered by the construction and operation of the Aspinall Unit (Blue Mesa, Morrow Point and Crystal Reservoirs), and by diversion and return flow features primarily related to irrigation in the areas surrounding Montrose and Delta (Figure 1). Cool stream temperatures resulting from changes to the basin hydrology (Stanford, 1994) have been identified as a significant impediment to re-establishment of pikeminnow habitat in the Gunnison River near Delta (Osmundson, 1999).

Records indicate that Colorado pikeminnow historically were found in the Gunnison River as far upstream as the Town of Delta (Quarterone, 1993), though recent studies indicate that pikeminnow are largely confined to downstream reaches of the river (Valdez et al., 1982, Burdick 1995). Osmundson (1999) notes that areas upstream of Whitewater through the Town of Delta show no reduction in forage-size fish and that the floodplain area near Delta provides the "most diverse physical habitat conditions in the Gunnison River" between Hartland Diversion and the mouth. The Hartland Diversion dam is located above the city of Delta, just below the mouth of Tongue Creek.

Results of Osmundson’s work indicate that increasing mean water temperatures at Delta by 1 ^{o}C in June, September and October, and by 2 ^{o}C in July and August, would increase the mean annual thermal units (ATU) from 32 to 46 units. Such an increase would put stream temperatures at Delta at a level similar to sites on the Yampa and Colorado Rivers which have abundant populations of pikeminnow.

Stream temperature in reservoir-regulated rivers is a function of several related variables. The “natural” mean water temperature is closely related to mean air temperature (Sinokrot and Stefan, 1993). Water released from a reservoir will tend to approach this natural or ambient water temperature as it travels downstream. The rate at which the waters warm, and the ability to achieve a specific temperature at a specific location, depends on release temperature, flow, and atmospheric conditions. In general, increasing reservoir release temperatures will result in warmer downstream temperatures. The relationship between release temperature and downstream temperature is nonlinear (e.g., a 1 ^{o}C increase in release temperature does not necessarily result in a 1 ^{o}C increase downstream) and is limited by the ambient atmospheric conditions. Reducing reservoir releases will also increase downstream temperatures. This is the result of a reduced volumetric heat capacity per unit surface area of stream, and of the slower rate at which the water travels downstream, thus increasing the time it is exposed to atmospheric heating.

There are potentially two ways that downstream temperature control can be achieved in the Gunnison River. These are to 1) *increase* the *temperature* of the water being released from the Aspinall Reservoirs, and/or 2) *decrease* the *amount* of water being released. Analysis of the potential for releasing warmer water is complicated by the physical characteristics of the Aspinall Unit reservoirs. If a temperature control device (TCD) solution was desired, it is not immediately clear which reservoir or reservoirs would need to be modified with such structures.

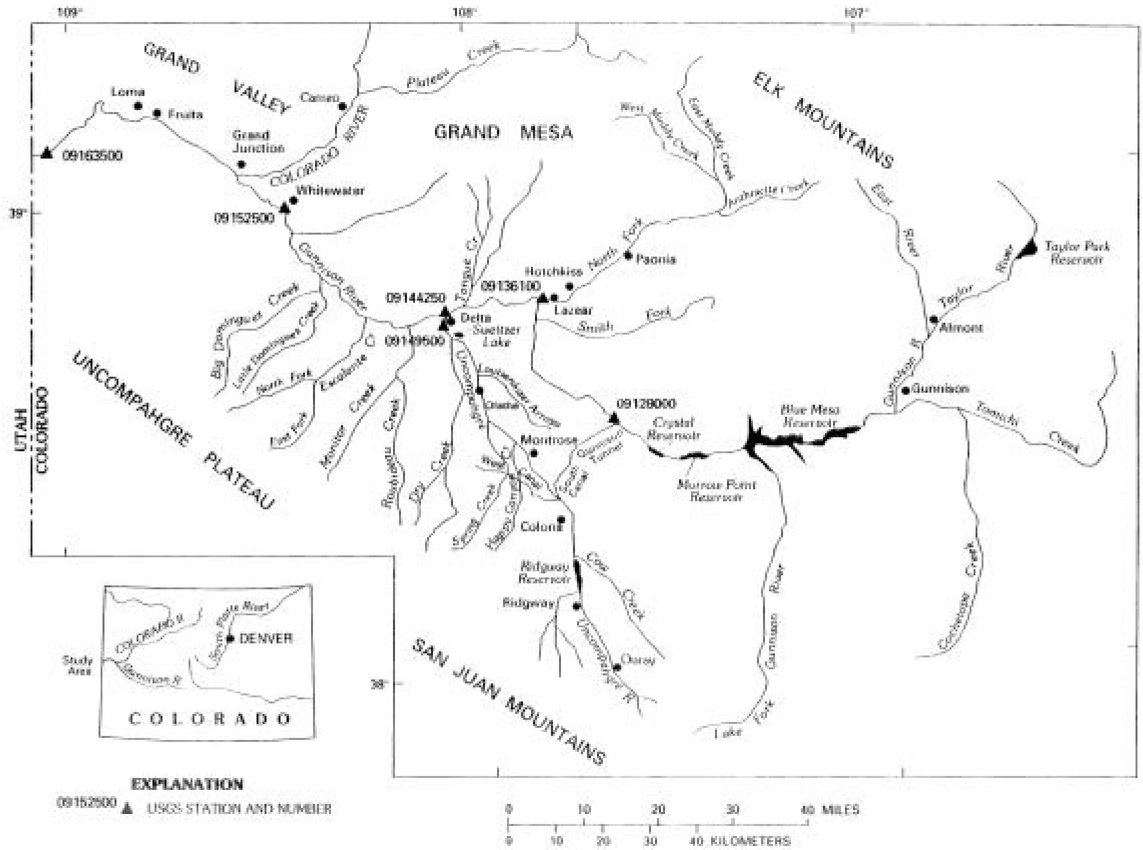


Figure 1. Gunnison River Basin (adapted from Butler, 2000).

Additionally, before any decision can be made to modify the system for purposes of temperature management, a whole host of other physical and institutional constraints must be taken into consideration. These constraints may include, but are not limited to, factors such as: water rights administration, hydropower generation, recreational fisheries (river and reservoir), reservoir recreation, flood control, and interstate and international compacts.

This report is structured as follows. The next subsection provides an overview of the project objectives. Section 2 addresses the data collection effort, and summary tables of data are provided in the Appendix. Section 3 provides and overview of the reservoir and river analyses, which are discussed in detail in Sections 4 and 5, respectively. Section 6 addresses a wide range of physical and institutional constraints on reservoir and river operations that may potentially limit the ability to control downstream temperatures. Section 7 summarizes the results of the analyses, and provides some broad recommendations to the members of the Recovery Program.

1.1 Statement of Need / Project Objective

The objective of this study is to determine the feasibility of increasing stream temperatures in the Gunnison River at and below Delta, Colorado through structural and / or operational modifications to the Aspinall Unit Reservoirs. The project is being approached in a two-step process. The first phase of the work, which this report summarizes, includes data collection and assessment; an overview of factors that may constrain the Program's ability to meet temperature objectives; a preliminary analysis of the data with the intent of gaining insight into the primary physical processes governing water temperature in the basin; and modeling recommendations for the second phase of the work.

The data assessment provided us with an understanding of the physical characteristics of the study area. As part of the data assessment process, we attempted to identify any previous modeling efforts in either the reservoirs or river reaches of interest.

The deliverables of this phase I study, which are reported in this document, are:

- Collection and assessment of existing data and models from the Gunnison Basin, including stream and reservoir temperatures, mainstem and tributary inflows, meteorological data, and any models of the reservoir / river system;
- A work plan outlining additional data collection and field work required to have a "complete" database for future modeling efforts;
- An analysis of non-physical factors which may influence temperature control, such as constraints on reservoir operations or water delivery obligations; and
- An initial assessment of the prospects for obtaining warmer stream temperatures at Delta and what methods are likely to be most effective (e.g., modification of reservoir release hydrograph vs. use of selective withdrawal for releasing warmer water).

Phase II of this project, if approved, would involve development and application of numerical models of the Gunnison system. Results from these model outputs in phase II would answer several questions, including:

- Would a TCD at Blue Mesa result in warmer release temperatures at Crystal?
- If so, how much warmer would they be?
- Would these warmer release temperatures translate into warmer river temperatures in the area around Delta?
- What are the benefits of a fixed versus variable height withdrawal structure?
- How would a TCD impact the thermal structure of the Aspinall reservoirs?

2. DATA COLLECTION

A significant data collection effort was undertaken for phase I of the project. The goal of the data collection task was to provide:

- A basis for determining whether or not additional field work was needed before a modeling effort could begin;
- A database from which any future temperature modeling effort could quickly and easily assemble data necessary for model development and execution; and
- A basis for preliminary analysis of temperature trends in the basin, from which an initial recommendation on the feasibility of obtaining warmer temperatures near Delta could be provided.

This report provides a summary of the data collected. Records of Gunnison River temperatures were obtained from George Smith of USFWS, and of Crystal, Morrow Point, and Blue Mesa reservoirs from Matt Malick of the National Park Service. Numerous other data sources were used as well, as outlined below and in the Appendix. Overall, the data appear to be good quality and should not be a limiting factor in the successful development of a set of mathematical models.

Types of data collected included time series records of stream flow, reservoir contents, stream and reservoir water temperatures, daily minimum, mean and maximum air temperatures, precipitation, wind speed and direction, and dewpoint. In addition, data on certain other physical parameters such as reservoir outlet structure elevation and streambed geometry were gathered.

A total of approximately 76 Megabytes of data in electronic forms were collected. These include several MSAccess databases and Excel spreadsheet files, as well as raw ASCII text files. Other formats of information include numerous written reports, information gleaned from various government web sites, and numerous emails and personal communications with individuals either involved in the Recovery Program or with other water related facilities in the Gunnison Basin.

For obvious reasons, we do not include the data in this report. However, data sources are listed in the references section, highlighted with and asterisk (*), and the Appendix provides summary tables of the larger data sets collected.

As part of the data collection exercise, we also attempted to identify past temperature modeling efforts in the Gunnison Basin. The only significant temperature modeling effort we know of is the CE-THERM model of Blue Mesa Reservoir developed by Brett Johnson of CSU (Johnson et al., 1996). This model is a one-dimensional (vertically layered) model of Blue Mesa, and has been used primarily to examine potential in-reservoir temperature impacts resulting from possible changes in reservoir release patterns. Although the model itself addresses in-reservoir temperature, it does not address potential impacts of a TCD.

3. ANALYSIS OVERVIEW

As stated previously, this project was split into two phases because the Recovery Program felt it would be wise to conduct a feasibility and scoping study of Gunnison river temperatures before investing the time and money in developing comprehensive models of the system. The results and recommendations from this first phase would then form the basis for deciding whether or not to pursue a more rigorous modeling exercise.

Given this objective, we conducted a limited analysis of the data to determine what, if any, conclusions could be drawn with respect to the prospects for increasing stream temperatures near Delta. There is considerable evidence that the Aspinall Unit reservoirs have impacted temperatures near Delta (e.g. Stanford, 1994, Osmundson 1999). What we want to evaluate here is the degree to which the reservoirs impact stream temperature, and whether or not structural or operational modifications to the reservoirs could be used to warm the river near Delta. Accompanying this central question are a host of other physical and institutional questions that need to be addressed.

Some of these basic questions and analyses that we have attempted to address include:

- What general trends in water temperatures can be discerned from the data?
- What are the impacts of season, release temperature, meteorological conditions, and flow on these trends?
- Are there significant tributary impacts?
- What does the thermal regime of the Aspinall Unit reservoirs look like?
- What immediate conclusions can we draw from the reservoir data?

Clearly some of these questions will require a more in-depth modeling exercise to address fully. However, some preliminary analysis of the data indicates that prospects are good for using the Aspinall reservoirs to obtain warmer stream temperatures near Delta. Again, we remind the reader that we are simply addressing whether or not temperature control is possible; there are a host of other factors both physical and institutional that may further constrain any temperature control options. The following data analysis is split into two sections, one focusing on reservoir temperatures, the other on river temperatures between Crystal Dam and the town of Delta.

4. TEMPERATURE ANALYSIS OF THE THREE ASPINALL UNIT RESERVOIRS

An analysis was conducted to determine how each reservoir affected Gunnison River temperatures. The data used for this analysis included electronic data from the National Park Service (Matt Malick), and U.S. Fish and Wildlife Service (George Smith). Information from several reports provided by Bret Johnson of Colorado State University were also used (Johnson, 1997, 1998, and 1999). The focus of this analysis was the summer months, which is when most of the available data were taken and is the subject of this report.

Figure 2 shows temperatures over time at two locations in the river-reservoir system. These locations include the Gunnison River inflows into Blue Mesa and Gunnison River below Crystal.

The impact of the three reservoirs is to cool the river, especially during the summer months when there is an estimated 3.5 °C difference in temperature between Blue Mesa inflows and Crystal releases. Also, it appears that the reservoir system causes a lag in the timing of when peak temperatures occur of about 1 month.

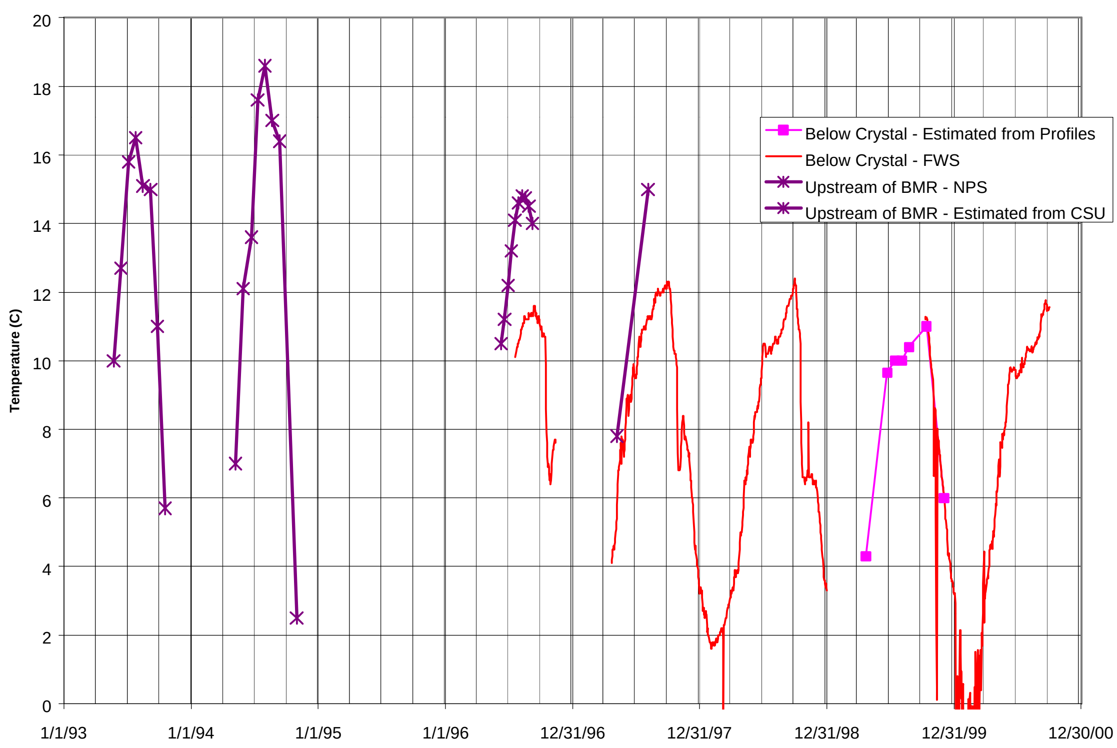


Figure 2. Gunnison River Temperatures Above and Below the Aspinall Unit Reservoirs.

To determine the impact of each reservoir, release temperatures from Blue Mesa and Morrow Point were added to Figure 2 (See Figure 3). Note that releases from Blue Mesa and Morrow Point were estimated using profile temperatures at the elevation of the outlet, taking reservoir elevation into account. Comparisons between profile data and observed releases when data were available indicated the validity of this technique.

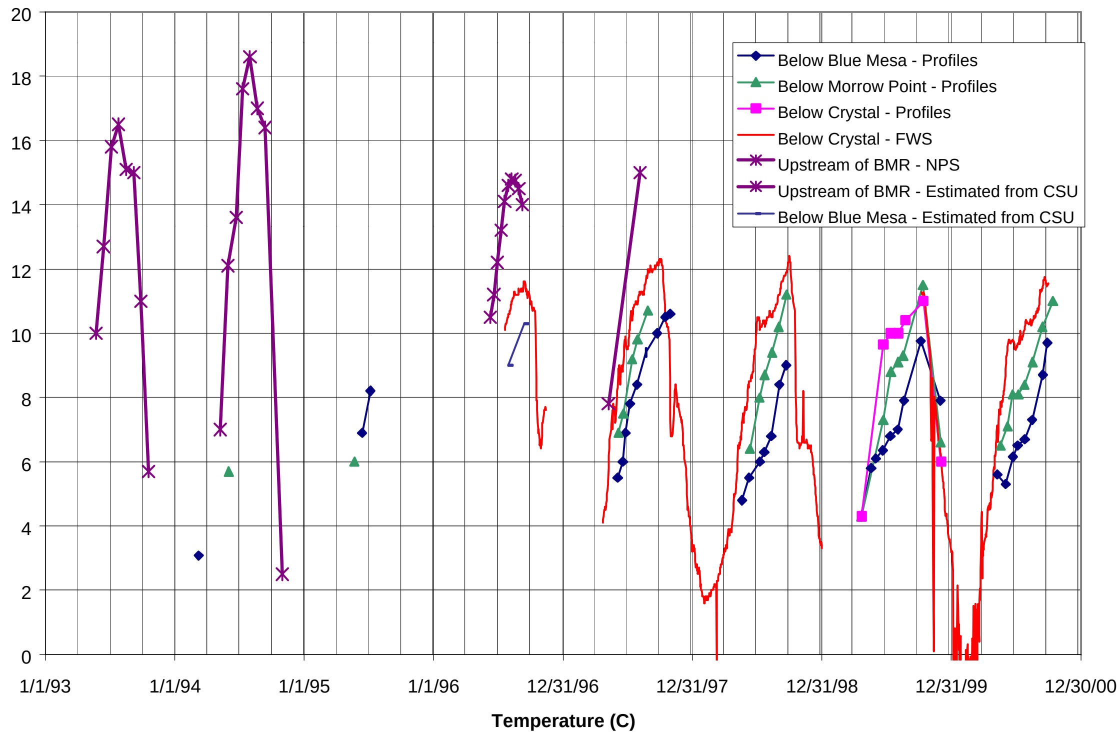


Figure 3. Gunnison River Temperatures (1993-2000).

It is evident from Figure 3 that the observed cooling is a result of Blue Mesa Reservoir. Release temperatures from Morrow Point are higher than those from Blue Mesa. Similarly, release temperatures from Crystal are higher than those from Morrow Point. Thus, a warming trend exists between the top of Morrow Point and the releases from Crystal. The temperature differences between each point are more pronounced in the earlier summer months and taper off in late summer.

A data analysis by reservoir may be found in the following sub-sections followed by a summary of the reservoir analysis.

4.1 Data Analysis by Reservoir - Blue Mesa

4.1.1 Physical Data - Morphometry, Hydrology, and Setting

Blue Mesa Reservoir is the largest reservoir in Colorado. It is a long impoundment, extending about 20 miles, and consists of three major sections or pools -- Iola, Cebolla, and Sapinero (Figure 4). The reservoir sits in a broad valley setting. Its morphometry is summarized in Table 1.

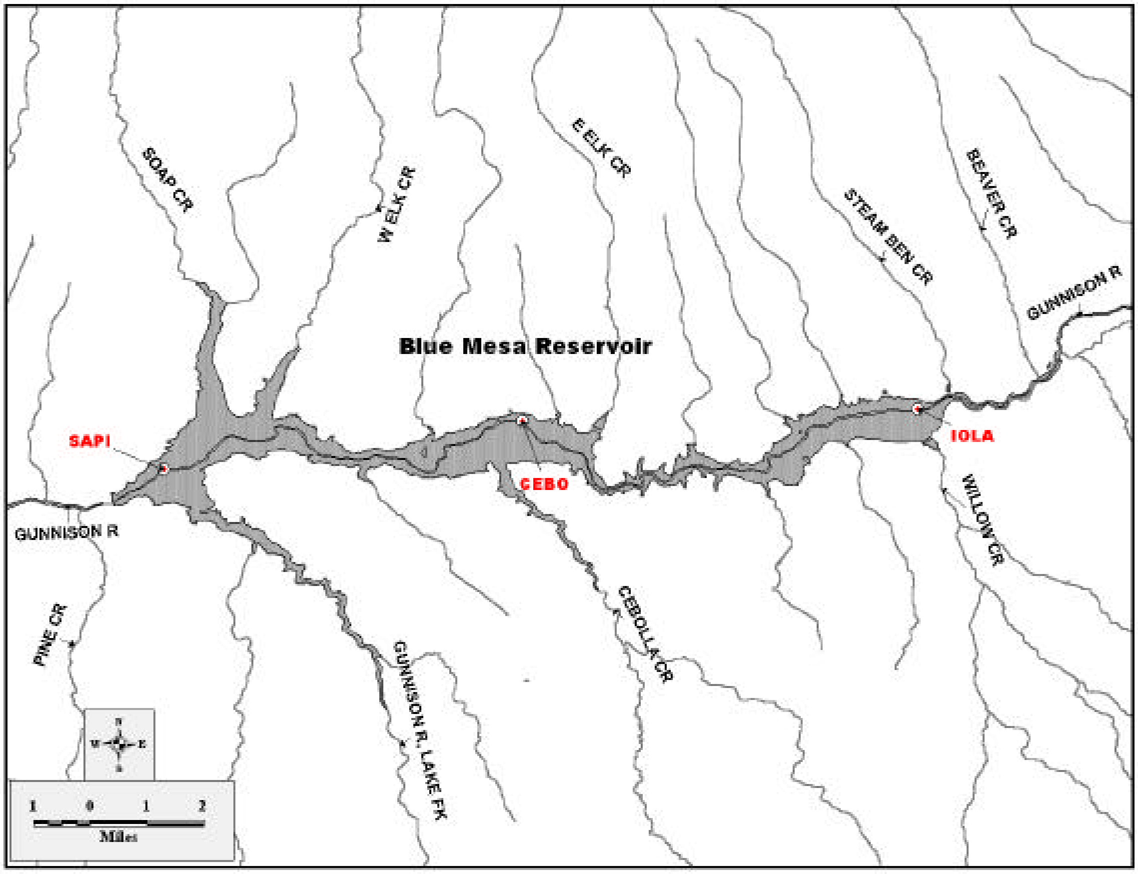


Figure 4. Blue Mesa Reservoir with Temperature Profile Collection Sites.

The hydrology of Blue Mesa Reservoir is also summarized in Table 1. Major tributaries into the reservoir include Cebolla Creek, Lake Fork of the Gunnison, Soap Creek, and West Elk Creek. The Gunnison River provides more than 50% of the inflow into Blue Mesa (National Park Service, 1996). A portion of this inflow is regulated by Taylor Park Reservoir, located on the Taylor River and another reservoir located on the Lake Fork of the Gunnison.

Inflows and releases from Blue Mesa Reservoir for the period 1995 through 2000 are displayed in Figure 5. Inflows peak around late-May / early June. Releases may peak anytime from June through the following winter, depending on flood control operations, summer demand and the following spring runoff forecast. The residence time of Blue Mesa is between 7 and 9 months, indicating that inflow / outflow dynamics should have a strong influence on reservoir hydrodynamics.

Table 1: Mean Annual Morphometric and Hydrologic Characteristics for Blue Mesa Reservoir During the Period 1969-2000

Parameter	Value (English)	Value (Metric)
Volume		
Maximum Total	940,800 AF	1.16×10^9 m^3
Mean Total	566,577 AF	0.70×10^9 m^3
Mean Epilimnion	166,577 AF	0.2×10^9 m^3
Mean Hypolimnion	400,000 AF	0.49×10^9 m^3
Surface area		
Maximum Lake	9,180 Acres	37.1×10^6 m^2
Mean	7,100 Acres	28.7×10^6 m^2
Thermocline	5,500 Acres	22.2×10^6 m^2
Elevation		
Maximum	7,519.4 ft (msl)	2,291.9 m (msl)
Mean	7,487 ft (msl)	2,282.1 m (msl)
Bottom	7,260 ft (msl)	2,212.9 m (msl)
Outlet	7,367 ft (msl)	2.245 m (msl)
Depth		
Mean lake	79.8 ft	24.3 m
Maximum lake	342 ft	104 m
Average thermocline depth	72 ft	22 m
Hypo thickness	72 ft	22 m
Flow		
Inflow	963,962 AF/yr	1.19×10^9 m^3/yr
Outflow	803,814 AF/yr	0.99×10^9 m^3/yr
Residence time		
Inflow (Volume/Inflow)	7 months	7 months
Outflow (Volume/Outflow)	8.5 months	8.5 months

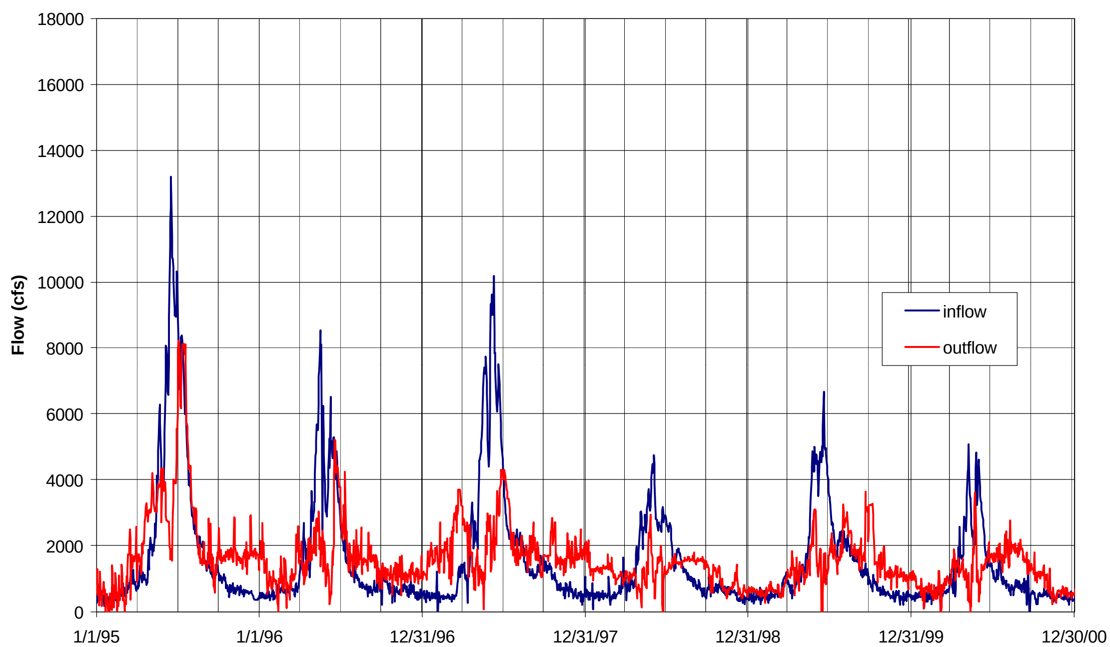


Figure 5. Blue Mesa Reservoir Inflows and Releases (1995-2000).

Since Blue Mesa Reservoir is the main storage facility for the Aspinall Unit, its water surface elevation fluctuates dramatically throughout the year (Figure 6). Low elevations typically occur in April/May and the highest water surface elevations typically occur in mid summer through early fall. This pattern corresponds to the predominant long-term use of the reservoir, which is providing irrigation water to users in Montrose, Delta, and Grand Junction areas. The lowest reservoir elevation occurred in 1984 when the reservoir dropped to 7,428 feet, 91 feet below the maximum surface elevation.

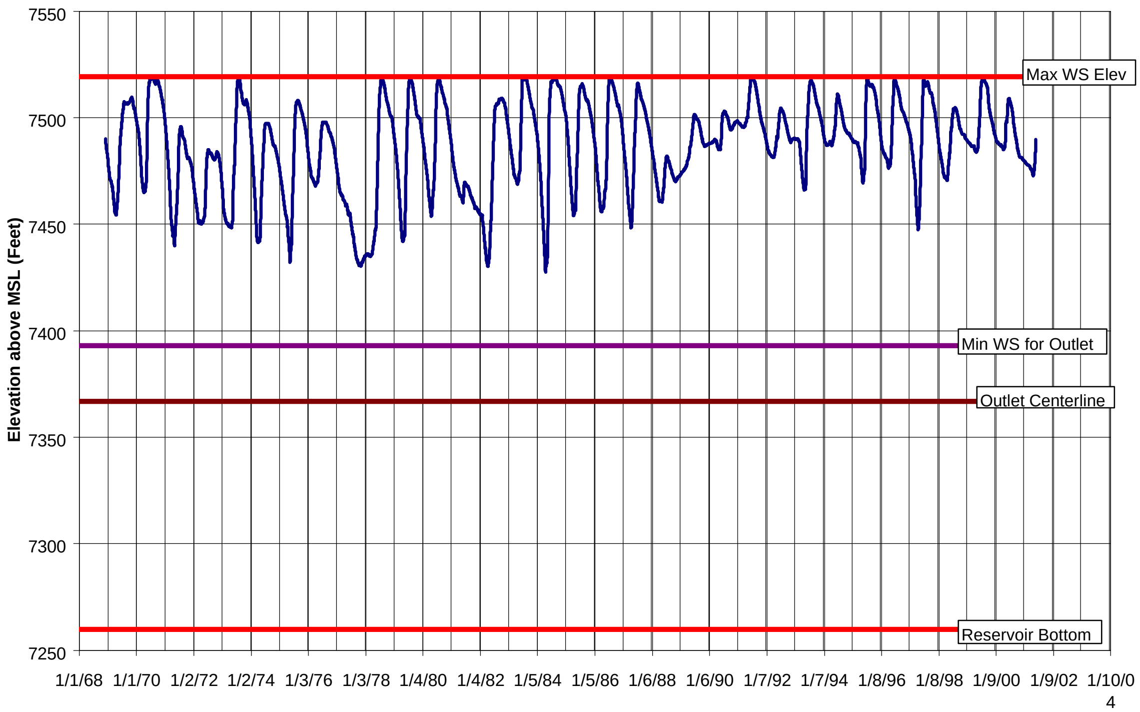


Figure 6. Blue Mesa Water Surface Elevation.

4.1.2 Temperature Data

Blue Mesa strongly stratifies during the summer (Figure 7). Profile data end before fall turnover but it is presumed that turnover occurs in late October.

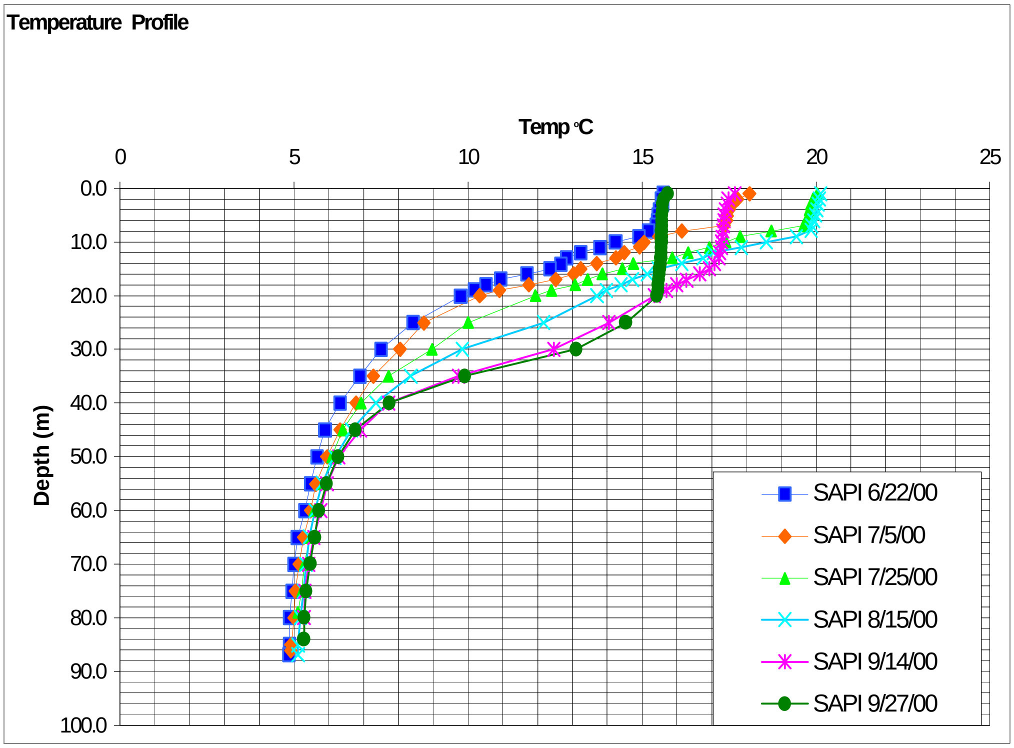


Figure 7. Temperature Profiles for Blue Mesa Reservoir (Sapinero Basin), 2000.

An analysis of temperature profile data for each of the three basins indicates that there is very little longitudinal variation in temperature. Bottom temperatures in the deepest part of the reservoir (Sapinero Basin) are very cold and stay relatively constant throughout the summer (Figure 7).

Over 50% of the tributary inflow comes from the Gunnison River (NPS, 1996), which in 1996 was the coldest of the four major tributaries (Cebolla, Soap, and Lake Fork) (Johnson, et al., 1997).

Numerous profiles were provided for the years 1997 - 2000 for Blue Mesa Reservoir. Of these years, 1997 runoff was well above average and 2000 runoff was well below average. Profiles for 1997 are displayed in Figure 8 and profiles for 2000 are shown in Figure 7. Estimated release temperatures during these two years are shown in Figure 9.

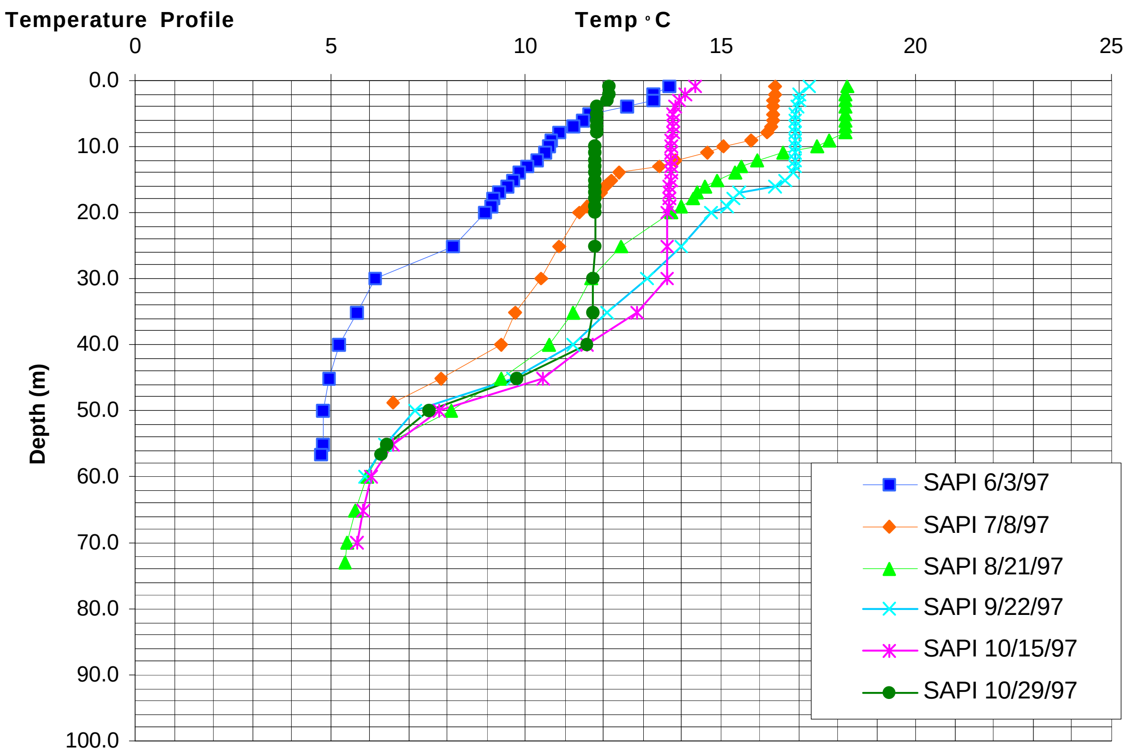


Figure 8. Temperature Profiles for Blue Mesa Reservoir (Sapinero Basin), 1997.

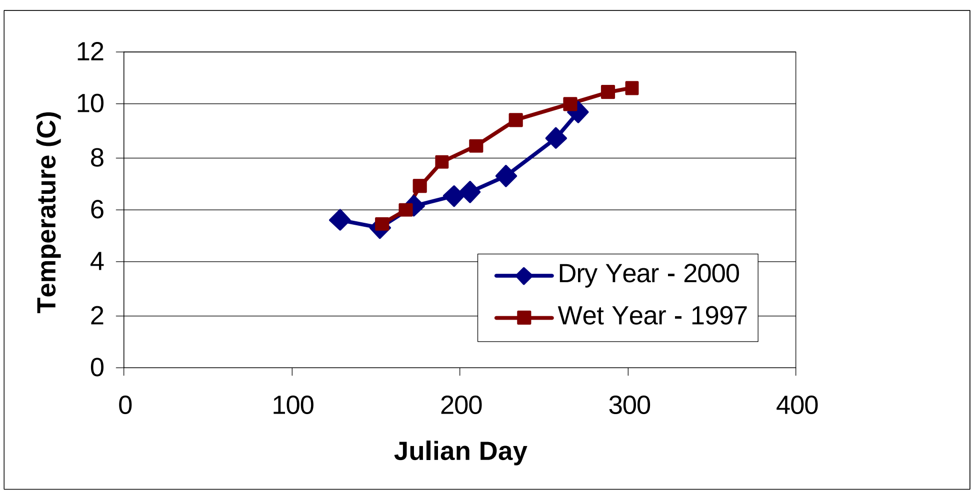


Figure 9. Estimated Release Temperatures from Blue Mesa Reservoir (1997 and 2000).

Note that the general shape of the profiles is different between the two years. This is further shown in Figure 10 displaying a July profile for each year.

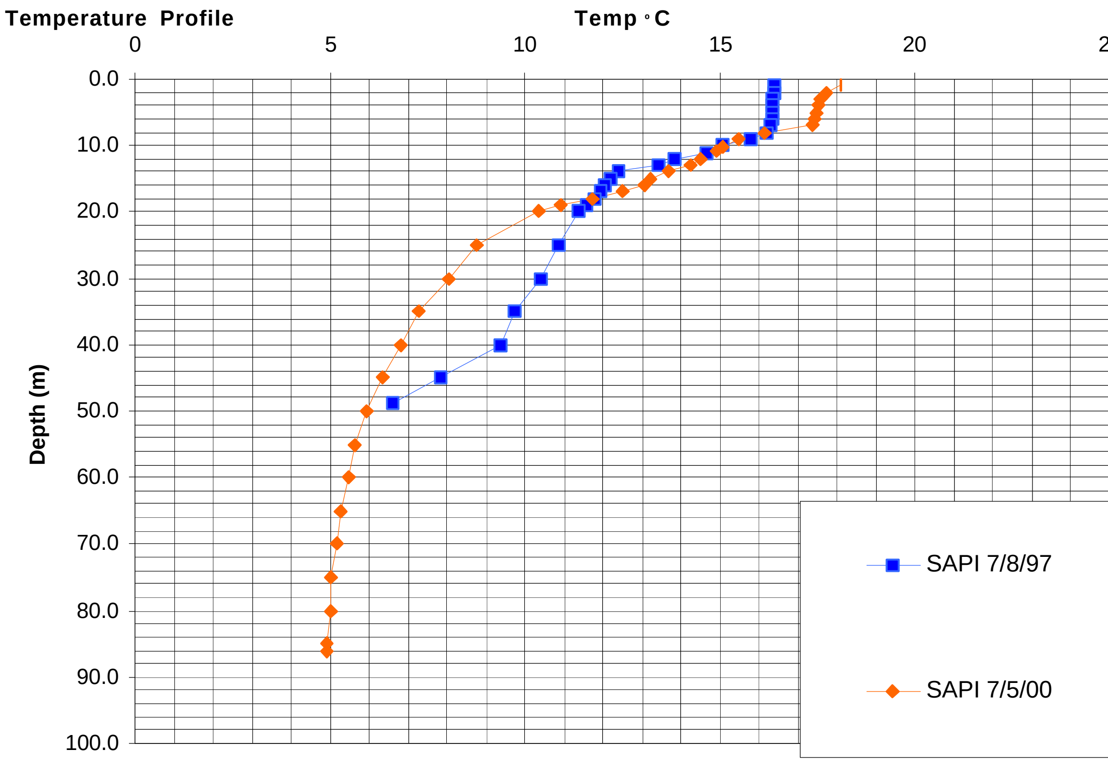


Figure 10. Two Profiles from Blue Mesa Reservoir (1997 and 2000).

This change in profile shape could be the result of increased inflows to the reservoir. Higher inflows can cause much turbulence and reduce the thermal gradient appreciably (Wetzel, 1983). This phenomena can result in having warmer temperatures at the same location in the upper hypolimnion (or where the outlet is in Blue Mesa) and thus impact release temperatures. For Blue Mesa, profiles indicate that releases were probably warmer during July, August, and September in the wet year of 1997 than they were in the dry year of 2000.

4.1.3 Blue Mesa Summary

Blue Mesa Reservoir is a very deep and large reservoir. During the summer, release temperatures are significantly cooler than the inflows to the reservoir from the Gunnison River (and probably all tributaries) due to the location of the reservoir outlet. Differences as great as 5.9 °C appear to occur near the end of July and then probably decrease until around the time of fall overturn.

Based on temperature profiles from 1997 and 2000, it appears that release temperatures may be warmer during wet year conditions in July, August, and September. Additional data would be required to more fully investigate this topic.

Assuming a constant distance between the outlet centerline and the minimum water surface, the reservoir outlet could be raised by 35 feet and still be able to release water at the lowest historical water surface elevations. Assuming that the outlet location change did not significantly impact the thermal structure of the reservoir (one should use a model to determine this), release temperatures could increase by approximately 3 °C in late summer for wet years (based on 1997 data) and 5 °C for dry years (based on 2000 data).

4.2 Data Analysis by Reservoir - Morrow Point Reservoir

4.2.1 Physical Data -- Morphometry, Hydrology and Setting

Morrow Point Reservoir is the second reservoir in the Aspinall Unit and is the primary hydropower producer. It is a long, narrow, river-run reservoir, surrounded by steep cliffs (NPS, 1996). The average width is about 1.5% of reservoir length. Although there are a couple of minor tributaries, the vast majority of the inflow comes from Blue Mesa Reservoir releases (88% since its closure). Figure 11 shows locations of data collection sites in the reservoir. Its morphology and hydrology is summarized in Table 2.

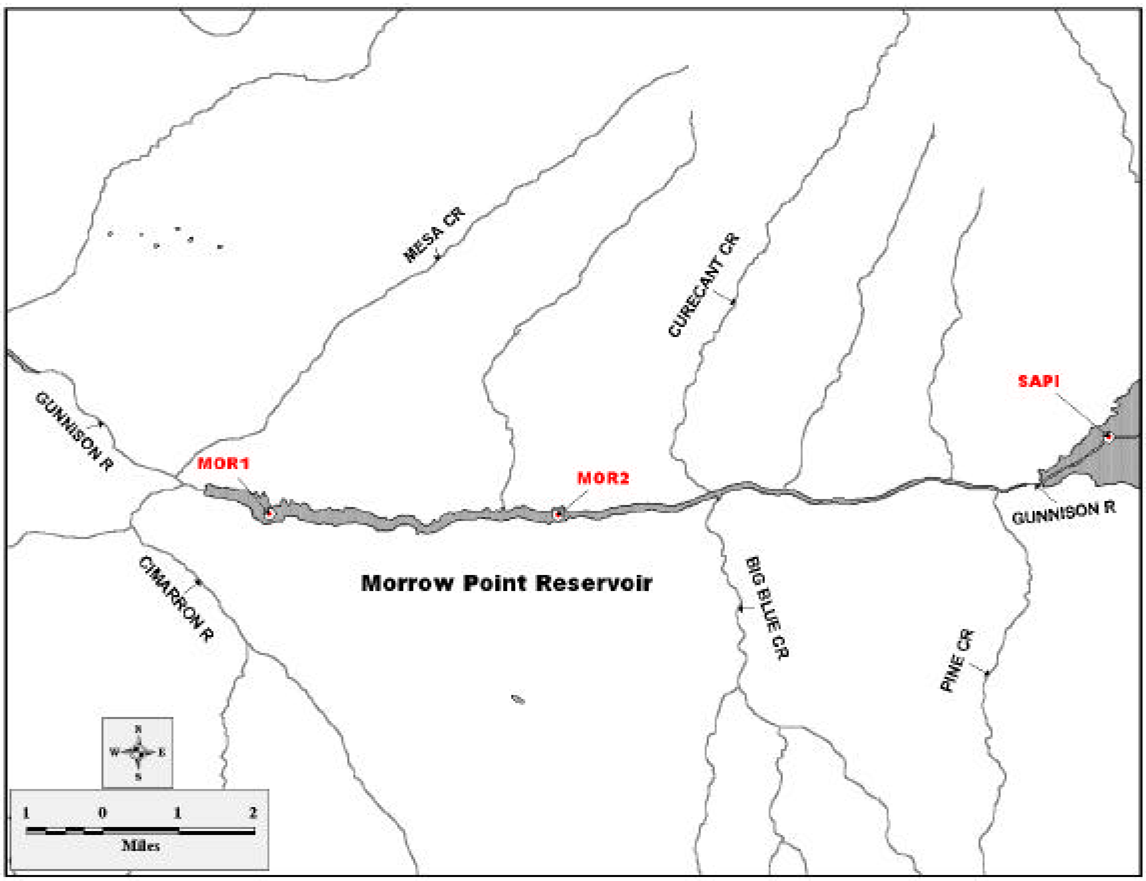


Figure 11. Morrow Point Reservoir with Data Collection Sites.

Table 2: Mean Annual Morphometric and Hydrologic Characteristics for Morrow Point Reservoir During the Period 1971-2000

Parameter	Value (English)	Value (Metric)
Volume		
Maximum Total	117,165 AF	0.14 x10^9 m^3
Mean Total	113,288 AF	0.14 x10^9 m^3
Surface area		
Maximum Lake	820 Acres	3.32 x 10^6 m^2
Mean	810 Acres	3.28 x 10^6 m^2
Elevation		
Maximum	7,160 ft (msl)	2,182 m
Mean	7,155 ft (msl)	2,181 m
Bottom	6,800 ft (msl)	2.073 m
Outlet	7,083 ft (msl)	2,159 m
Depth		
Mean lake	146 ft	44.5 m
Maximum lake	400 ft	122 m
Flow		
Inflow	1,087,374 AF/yr	1.34 x 10^9 m^3/yr
Outflow	1,086,887 AF/yr	1.34 x 10^9 m^3/yr
Residence time		
Inflow (Volume/Inflow)	1.25 months	1.25 months
Outflow (Volume/Outflow)	1.25 months	1.25 months

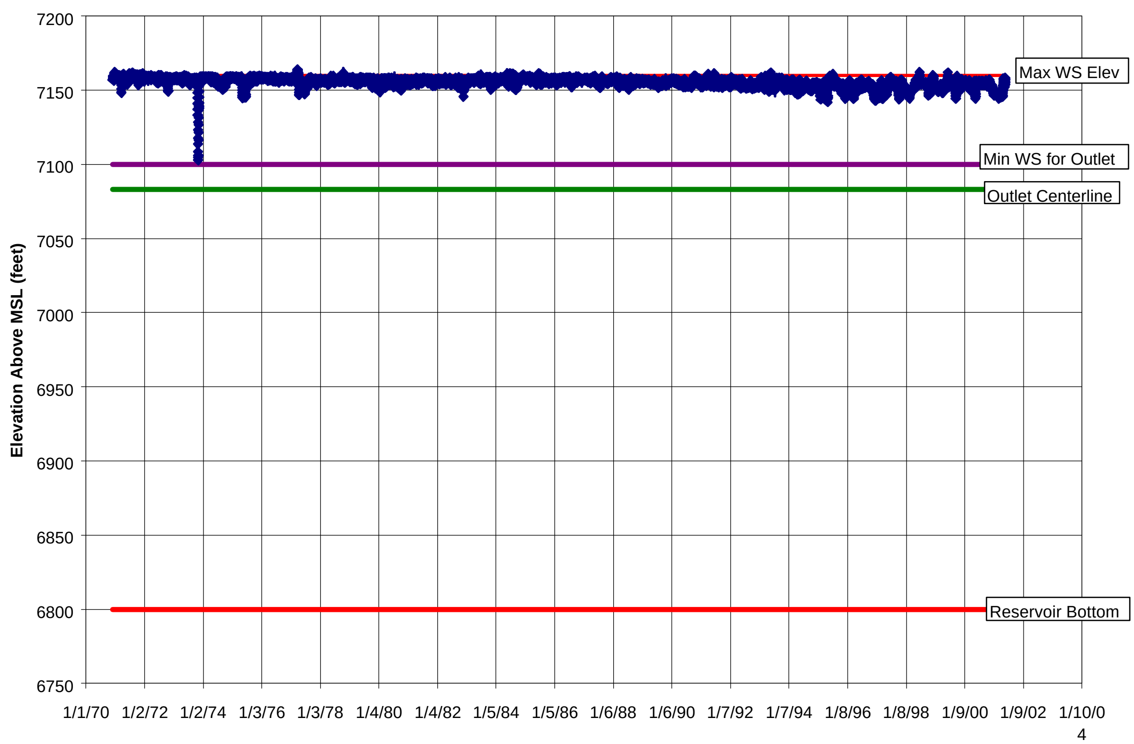


Figure 12. Water Surface Elevations for Morrow Point Reservoir.

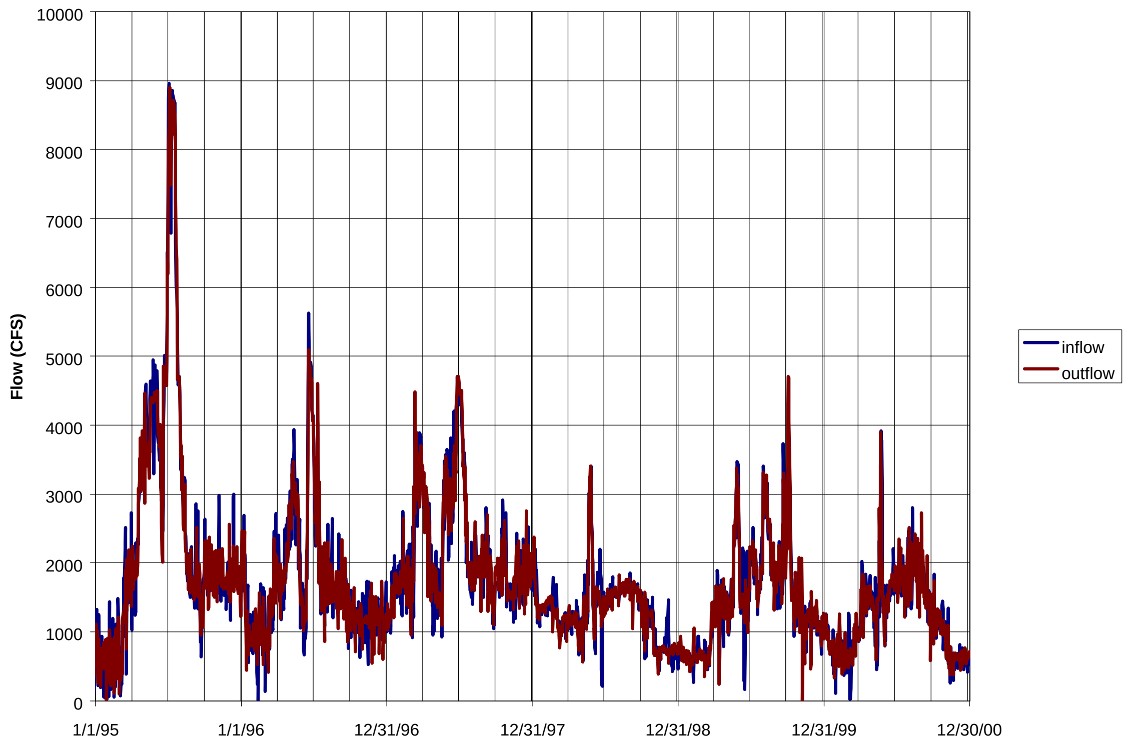


Figure 13. Inflow and Releases for Morrow Point Reservoir (1995-2000).

Daily water surface elevations stay relatively constant, varying at the most 20 feet since 1990 (Figure 12). Due to how the reservoir is operated however, there is significant diurnal fluctuation in the water surface elevation. Inflow and outflow patterns are similar and follow the release pattern of Blue Mesa Reservoir (Figure 13).

4.2.2 Temperature Data

There are two main sampling sites (Figure 11) -- one at Hermits Rest (MOR1) and the other at Kokanee Bay (MOR2). Temperature profiles for the Hermits Rest site are shown in Figure 14 for 2000. Analysis of the two sites shows little if any longitudinal variation.

Note the formation of a second metalimnion. It is probable that the large volume of water entering Morrow Point dramatically disrupts the more classic stratification pattern associated with temperate lakes. According to Wetzel, thermal stratification can be modified by inflow-outflow relationships, particularly if the influent volume is large in relation to the volume of the epilimnion and the inflow temperatures are less than those in the epilimnion. This is definitely the case for Morrow Point where the residence time is less than 6 weeks and inflows enter at cold temperatures from Blue Mesa. Inflows from Blue Mesa plunge and enter Morrow Point in the vicinity of the lower metalimnion. This interflow continues to have a significant impact for the 11.5 miles down to the Morrow Point dam.

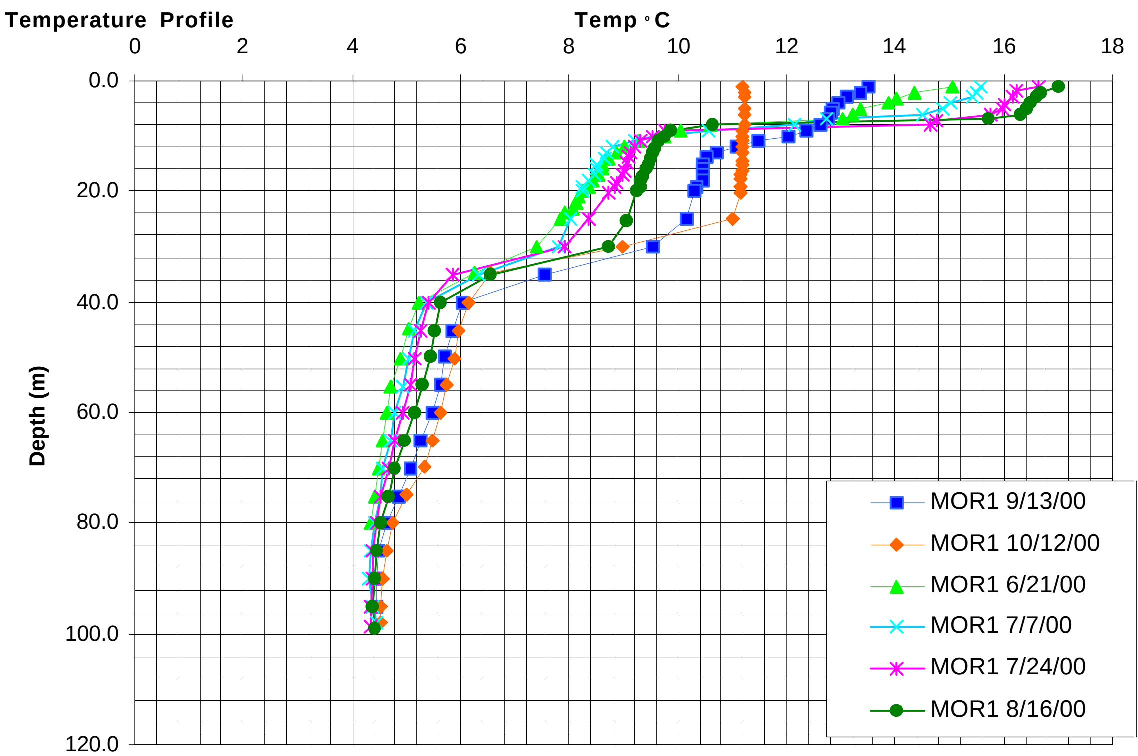


Figure 14. Morrow Point Temperature Profiles at Hermits Rest, 2000.

Releases occur at about 7,083 feet, above the interflow plunge point (the approximate elevation at which water entering the reservoir is submerged to due to its mass), where the water is warmer. Release temperatures are in general 1 to 2 °C warmer than the inflow during the summer months (Figure 3). As is the case with Blue Mesa, estimated release temperatures were warmer during the wet year of 1997 (July and August) compared to the dryer year of 2000 (Figure 15).

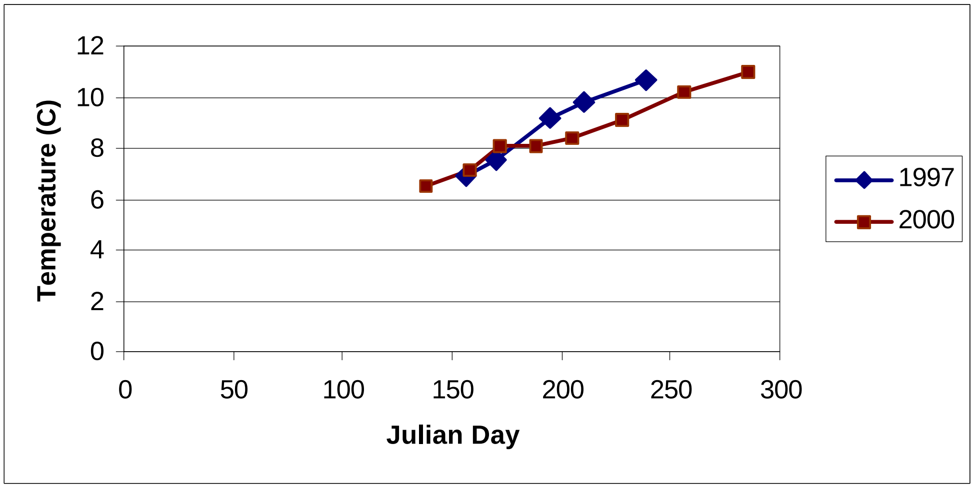


Figure 15. Estimated Release Temperature Comparison - Morrow Point Reservoir.

4.2.3 Summary

Conclusions from the data analysis described above include:

- Blue Mesa Reservoir releases significantly impact the thermal structure of Morrow Point Reservoir, creating an additional metalimnion;
- Releases from Morrow Point were about 1-2 °C warmer than the releases from Blue Mesa; and
- Estimated Morrow Point release temperatures were warmer during the wet year of 1997 compared to the dryer year of 2000 in July and August.

4.3 Data Analysis by Reservoir - Crystal Reservoir

4.3.1 Physical Data -- Morphometry, Hydrology and Setting

Crystal Reservoir is the third reservoir in the Aspinall Unit and serves as a re-regulating reservoir for Morrow Point releases (Figure 16). Like Morrow Point, Crystal Reservoir is long and narrow and surrounded by steep cliffs. The average width is about 2% of reservoir length. In addition to the releases from Morrow Point (supplying over 80% of the inflow), flows from the Cimarron River enter the reservoir along with other minor tributaries. Cimarron River has been noted as supplying a large sediment load to the system. The morphology and hydrology of Crystal Reservoir are summarized in Table 3.

Table 3: Mean Annual Morphometric and Hydrologic Characteristics for Crystal Reservoir During the Period 1980-2000

Parameter	Value (English)	Value (Metric)
Volume		
Maximum Total	25,273 AF	31.0×10^6 m^3
Mean Total	16,274 AF	20.1×10^6 m^3
Surface area		
Maximum Lake	300 Acres	1.2×10^6 m^2
Elevation		
Maximum	6,755 ft (msl)	2,059 m
Mean	6,750 ft (msl)	2,057 m
Outlet	6,680 ft (msl)	2,036 m
Depth		
Mean lake at full pool	84.2 ft	25.7 m
Maximum lake	~100 ft	30.5 m
Flow		
Inflow	1,300,368 AF/yr	1.6×10^9 m^3/yr
Outflow	1,300,584 AF/yr	1.6×10^9 m^3/yr
Residence time		
Inflow (Volume/Inflow)	0.15 months	0.15 months
Outflow (Volume/Outflow)	0.15 months	0.15 months

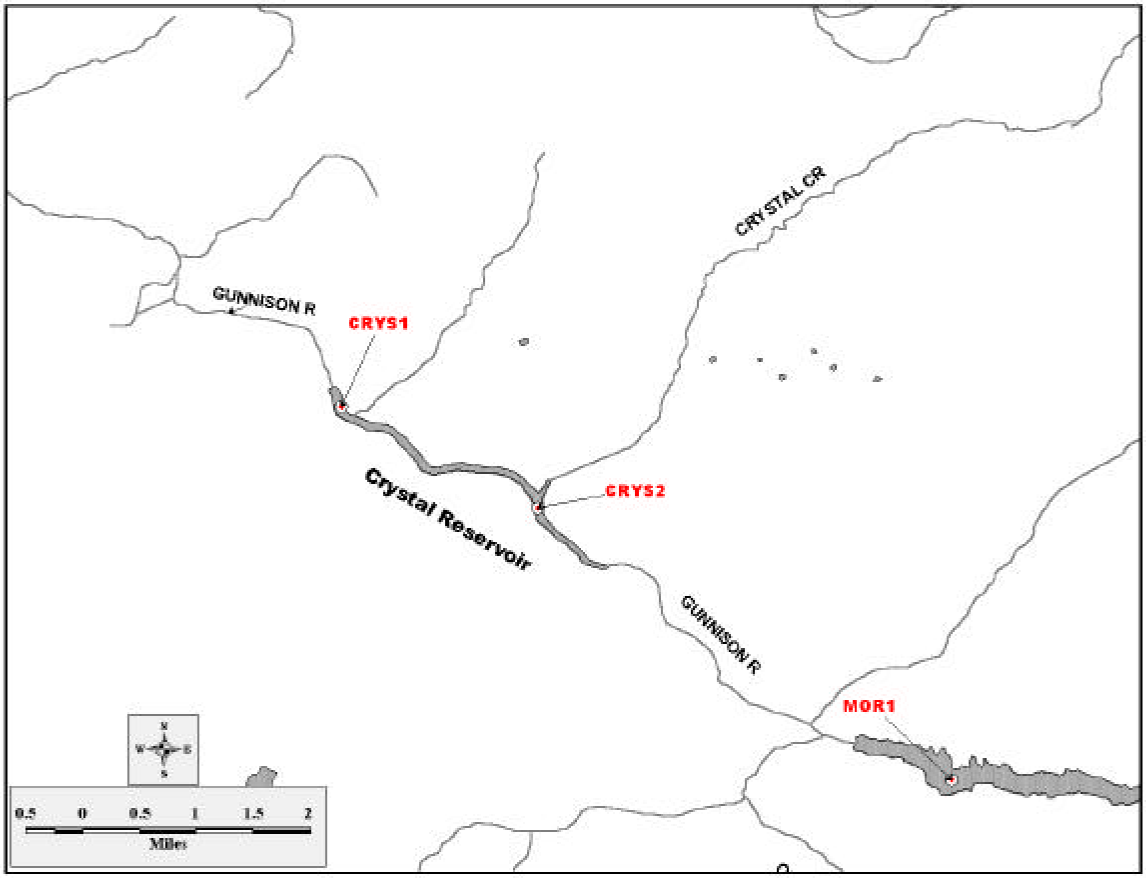


Figure 16. Crystal Reservoir with Data Collection Sites.

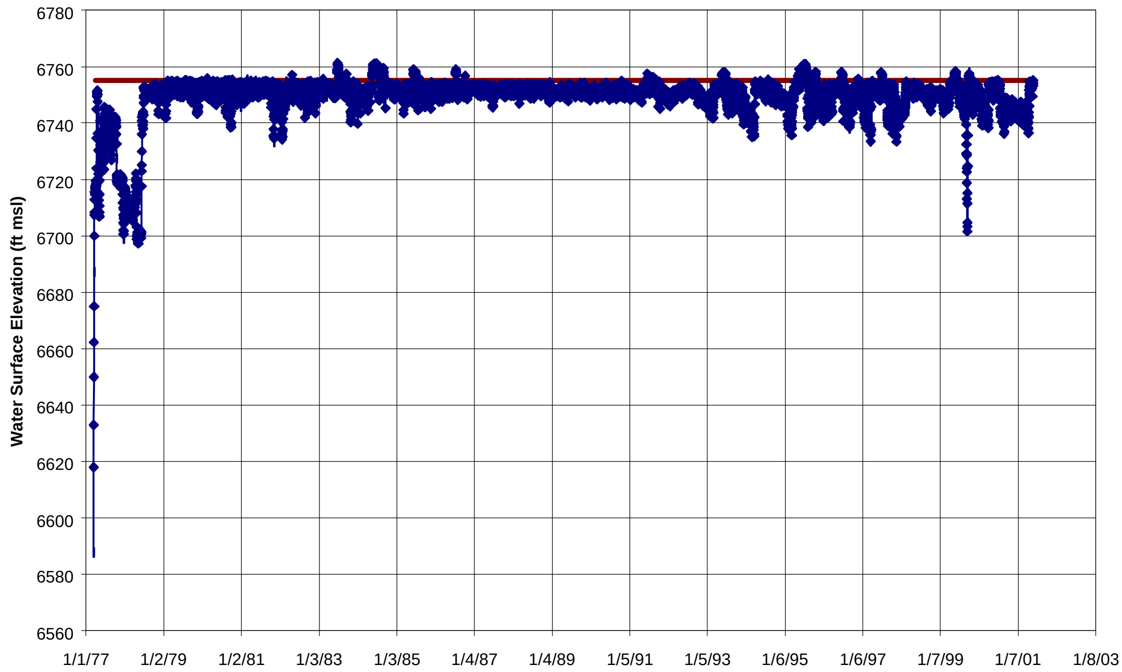


Figure 17. Crystal Reservoir Water Surface Elevations.

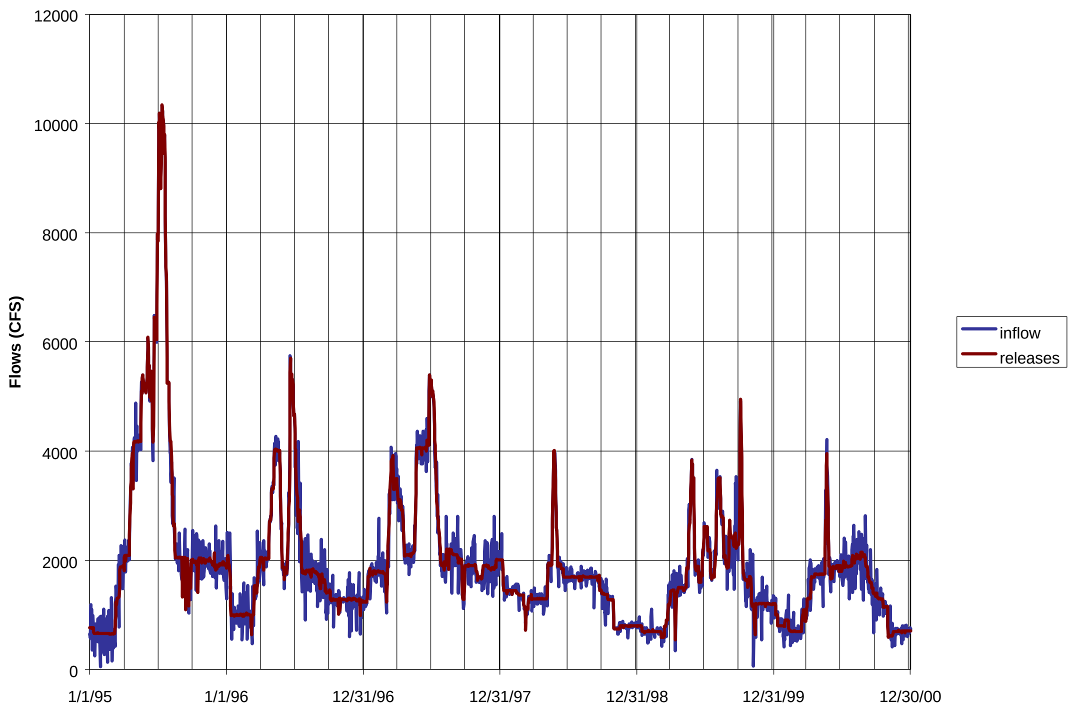


Figure 18. Crystal Reservoir Inflows and Releases (1995-2000).

Surface water elevations fluctuate slightly on a daily basis but experience significant diurnal variations (Figure 17). Inflows and outflows follow the same patterns as the outflows from Blue Mesa Reservoir (Figure 18).

4.3.2 Temperature Data

There are two main sampling sites at Crystal Reservoir -- one at the dam (CRYS1) and the other at Crystal Creek (CRYS2). Temperature profiles for site at the dam are shown in Figure 19 for 2000. Analysis of the two sites shows little if any longitudinal variation.

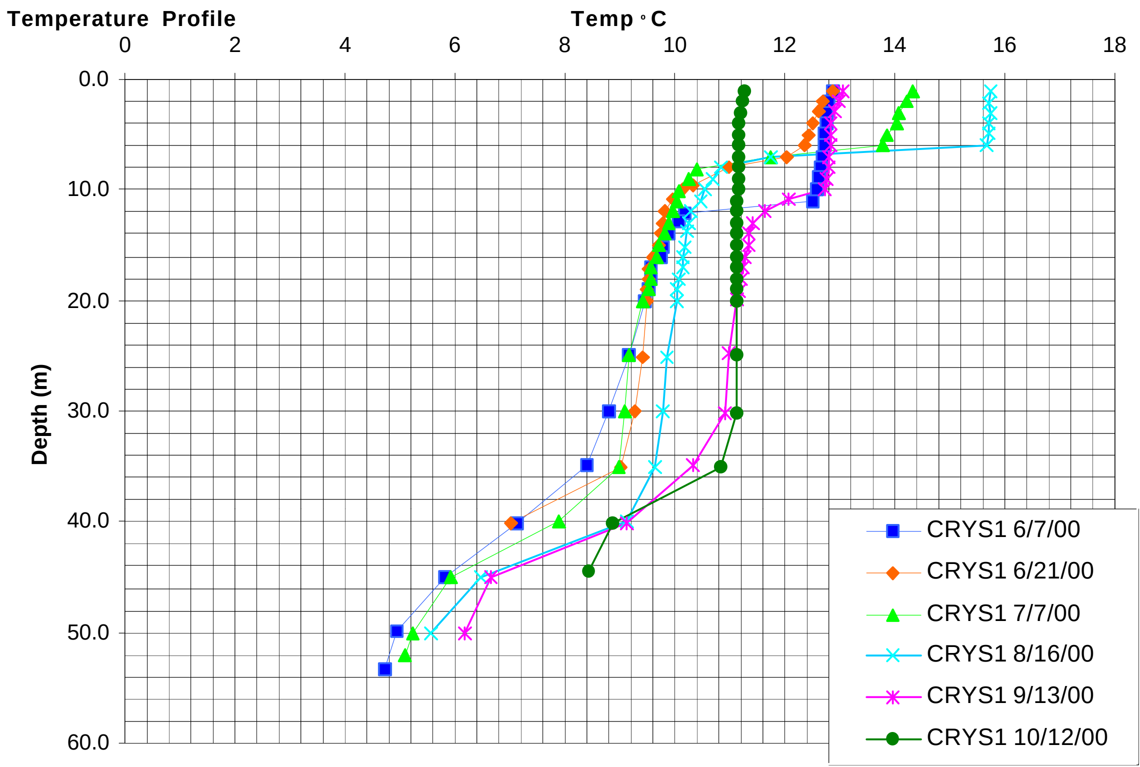


Figure 19. Crystal Reservoir Temperature Profiles Near the Dam (2000).

As with Morrow Point Reservoir, a second metalimnion forms. In addition, observed release temperatures follow the same pattern as Blue Mesa Reservoir and Morrow Point in that they are warmer during 1997 (wet year) than they were in 2000 (dry year) during the months of July, August, and September (Figure 20). Note however, that during the months of May and June, temperatures were warmer during the dry year.

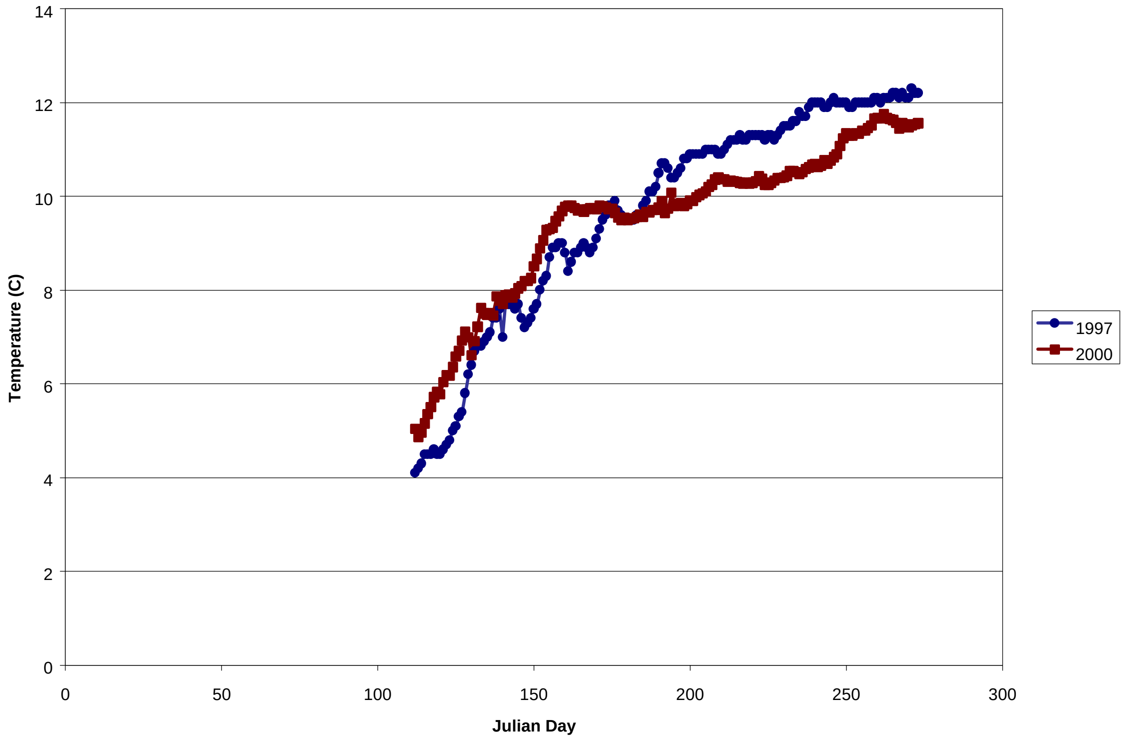


Figure 20. Crystal Reservoir Release Temperatures (1997 and 2000).

4.3.3 Summary

Conclusions from the data analysis described above include:

- Blue Mesa Reservoir releases significantly impact the thermal structure of Crystal Reservoir, creating an additional metalimnion;
- Releases from Crystal Reservoir were about 0.5-2 °C warmer than the releases from Morrow Point; and
- Crystal Reservoir release temperatures were warmer during the wet year of 1997 compared to the dryer year of 2000 during the months of July, August, and September. The opposite was true for May and June.

4.4 Discussion and Conclusions

A summary of some of the points made in this section include:

- Crystal Reservoir release temperatures are cooler than the Gunnison River inflows into Blue Mesa Reservoir;
- The impact of Blue Mesa Reservoir is to decrease water temperatures in the Gunnison River during the summer. The impact of Morrow Point is to increase Gunnison River

temperatures over the releases from Blue Mesa. The impact of Crystal is to increase Gunnison River temperatures over the releases from Morrow Point;

- Release temperatures were warmer in the wet year of 2000 versus the dryer year of 1997;

- Releases from Blue Mesa significantly impact the thermal structure of both Morrow Point and Crystal Reservoirs;

- Installation of a TCD on Blue Mesa should result in increased release temperatures. This modification may impact the thermal structure of Blue Mesa and a model would be needed to determine this.

- A TCD on Blue Mesa may impact the reservoir fishery. Potential impacts include alteration of zooplankton production dynamics, fish distribution and feeding behavior, predator-prey interactions among lake trout and kokanee salmon, and possible changes to fish entrainment (Brett Johnson, personal. communication. 2002).

- Taking warmer water from Blue Mesa and sending it through Morrow Point and Crystal should result in warmer releases from Crystal Reservoir but a modeling effort should be conducted in order to determine the change in thermal structure in the downstream reservoirs; and

- The Aspinall Unit needs to be considered as a system in order to determine the impacts of management strategies to increase Crystal release temperatures. Each reservoir should be modeled to predict the impacts.

5. RIVER TEMPERATURE ANALYSIS

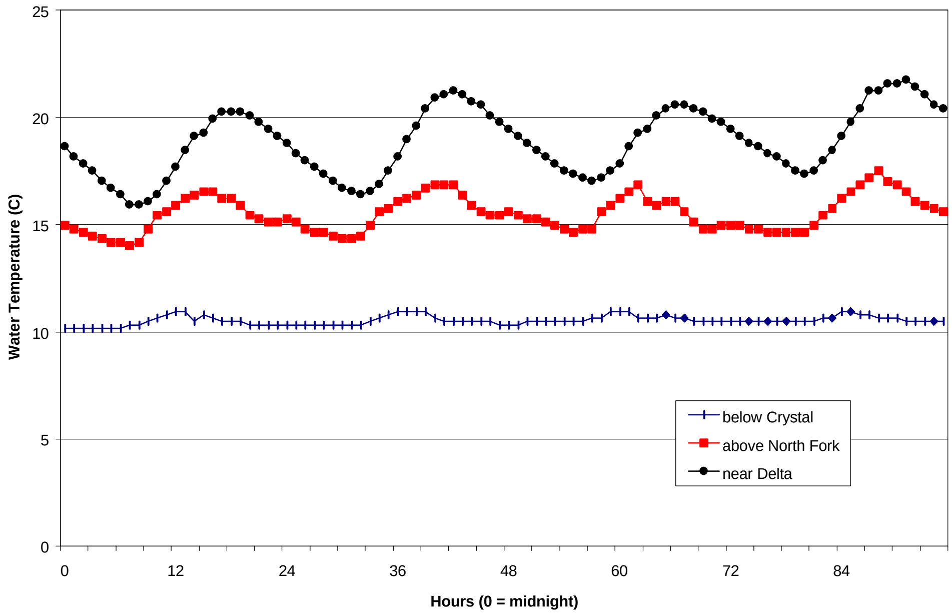
5.1 Background on Physical Processes

The ability to control water temperatures in reservoir-regulated rivers depends on numerous physical factors. Meteorology, hydrology, geology, geography, geomorphology, and riparian conditions will all impact heating and cooling rates. Atmospheric fluxes are the primary catalyst in determining water temperature, although significant heat flux may also occur into and out of the streambed, and is especially important in shallow streams, due to direct heating of the bed by solar radiation (e.g., Jobson, 1977). Variations in stream water temperatures tend to follow annual and diurnal variations in mean air temperatures. Diurnal variations are caused primarily by heating of the water by incoming longwave and shortwave radiation, and heat transfer into the stream from the streambed. Heat loss occurs through convection and evaporation at the water surface, and through conductive losses into the streambed when the overlying water is warmer than the bed surface.

The impact of a reservoir on stream temperatures downstream will vary depending on a number of factors including residence time, total depth, withdrawal depth, and physiographic setting. In most reservoir-regulated rivers in the Colorado Basin, summer water temperatures are significantly colder than those in similar unregulated river reaches, and winter temperatures are somewhat warmer. Cold hypolimnetic releases made in warmer months will warm as they travel downstream, eventually assuming a "natural" ambient water temperature that mimics to a degree the atmospheric pattern of diurnal heating and cooling.

Modifying releases from a reservoir, either through changing flows or use of a temperature control device, can be used to control downstream temperatures. However, this ability is limited by influences of tributary inflows, atmospheric and other heat flux components, and other river gains or losses, which eventually become the dominant forces determining river temperatures. Sinokrot and Stefan (1993) term reaches where water temperatures are directly influenced by reservoir releases as "thermal transition reaches".

A Thermograph showing diurnal variations in stream temperatures is shown in Figure 21. These data are from the three FWS temperature collection sites between Crystal and Delta, from early July of 1998. This figure is instructive in both the particular physiography of the Gunnison and in thermal effects of reservoirs in general. The site below Crystal shows almost no diurnal variability from atmospheric heating. The proximity of the recording device to Crystal Dam provides little time for those waters to warm. As released water travels downstream, it not only warms in terms of its daily average, but also takes on a more natural diurnally varying pattern of temperatures, with daily highs occurring in late afternoon and lows in morning hours. We hypothesize that the sharp drop in water temperatures observed in early afternoon at the North Fork site is due to the sun's incidence angle and canyon walls quickly causing complete shading on the river. The Delta site shows a more typical thermograph, with both solar radiation and air temperature playing primary roles in the diurnal pattern.



-4, 1998.

5.2 Thermal Characteristics of the Gunnison River from Crystal Dam to Delta

Water released from Crystal Dam flows generally northwest through Black Canyon of the

the Gunnison. The Black Canyon is a deeply incised gorge, and shading due to the canyon walls sev
confluence the river is contained by the canyon, and there is essentially no floodplain until below the confluence. From the confluence, the river bears due west, assumes a
wer gradient, and takes on a more meandering character, although lateral movements are still limited by low escarpments. The reaches below the town of Austin

kilometers above the confluence down through the town of Delta, direct radiative heating

slower, and would thus be expected to warm more quickly than through the Black Canyon reach.

Water temperature data from four locations on the Gunnison River were examined in this component of the work. These sites include three sites between Crystal and Delta: At

farther downstream, near Grand Junction. These data were collected primarily by Fish and Wildlife, and were provided to us in both daily average and raw hourly format by George Smith. Because the months June through October were identified by Osmundson (1999) as candidate months for increasing stream temperatures, our analysis is limited to those periods.

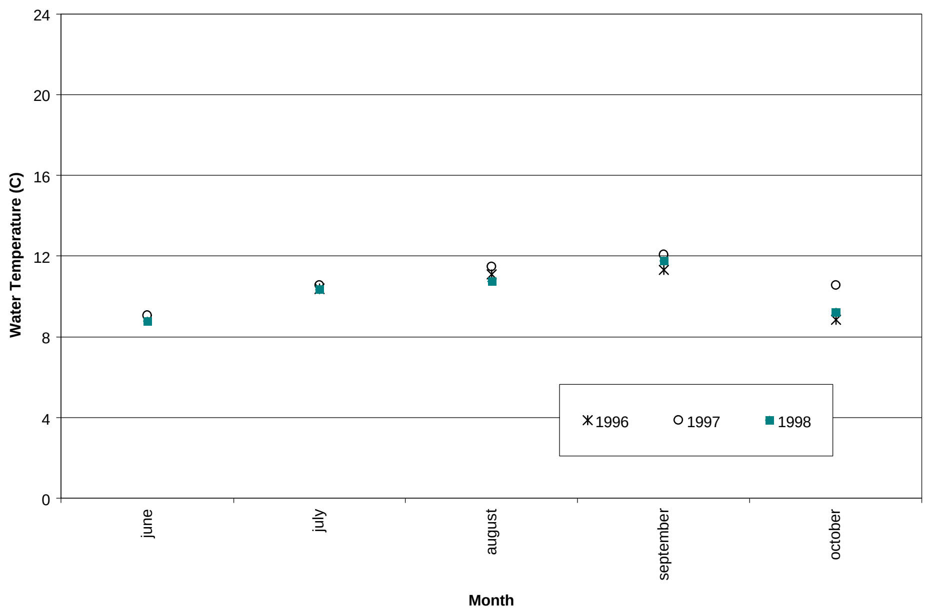


Figure 22. Average Monthly Stream Temperatures Below Crystal Dam.

Figures 22 - 25 show the average monthly temperatures for various years during the period 1992-1999. Release temperatures from Crystal Dam, although from a limited period of record, show a gradual increase in average temperature through the summer months (Figure 22). This warming is likely the result of two features of the system: reservoir surface warming resulting in conductive heat transfer to the hypolimnion of all the reservoirs, and drawdown of Blue Mesa, which brings warmer surface waters closer to the intake structures of the dam. Note that by October, releases have cooled, likely due to significant decrease in atmospheric heating and reservoir turnover.

Figure 23 shows temperatures at the second collection site, just above the North Fork. Temperatures here show more variation by month than at the Crystal site, and also exhibit an earlier occurrence of maximum temperatures. This earlier peaking is indicative of the shorter term impacts of atmospheric heating on the river itself, as opposed to that seen in the reservoirs, where thermal inertia delays the maximum temperatures later into the season. June and July show significant variation in mean monthly stream temperatures, as impacts of variable snowpack runoff timing and magnitude in tributary streams play a role in determining water temperature. Note that 1997, which was a very large runoff year, exhibits a marked departure from 1996 and 1998. Hydrologically wet years tend to result in more throughput of water from reservoirs, which slows the warming process, and also results in prolonged and larger magnitude tributary inflows. It is likely that the combination of higher than normal tributary flows combined with high reservoir releases through July caused lower than typical mean monthly stream temperatures at the North Fork site. Interestingly, after runoff has occurred and the reservoirs are full, the data show remarkably similar temperatures through August and September.

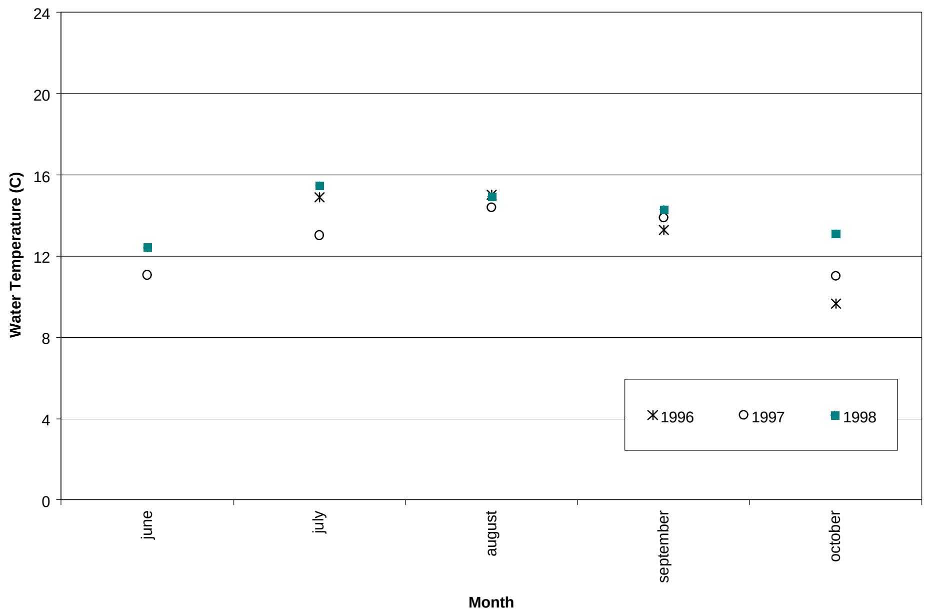


Figure 23. Average Monthly Stream Temperatures Above the North Fork Confluence.

Figures 24 and 25 are from the Gunnison River near Delta and Gunnison River near Grand Junction, respectively. The Delta data are recorded below the confluence of the Gunnison with the Uncompahgre. Temperatures at Delta and Grand Junction show much the same seasonal pattern as the North Fork site. Peak runoff, particularly from unregulated tributaries, during June and July results in large variations in mean monthly temperature from year to year, with higher temperatures generally corresponding to lower runoff volume years. From August through October, however, regulated reservoir releases become the dominant factor influencing water temperatures. Reservoir releases to downstream users during these months vary less on a monthly or seasonal basis compared to snowmelt runoff peaks, and thus we see very similar temperature regimes during the late summer months.

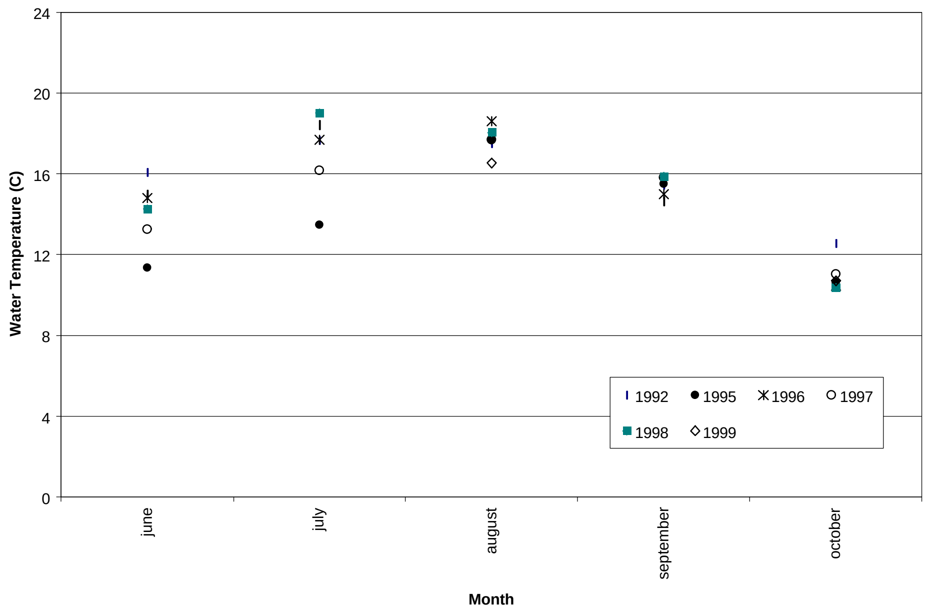


Figure 24. Average Monthly Stream Temperatures Near Delta, Colorado.

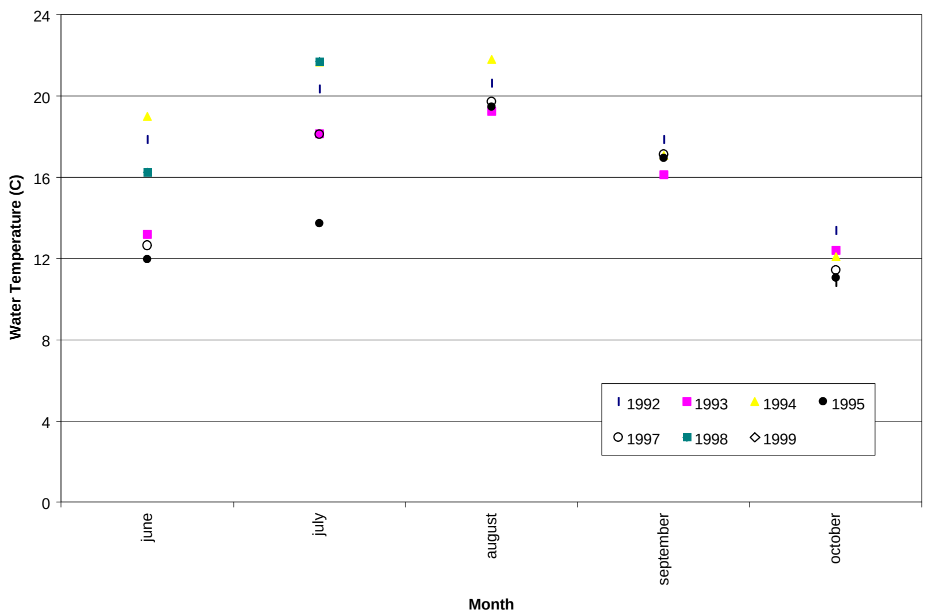


Figure 25. Average Monthly Stream Temperatures Near Grand Junction, Colorado.

One of the early concerns expressed by members of the Recovery Program with respect to temperature management was the degree to which tributary flows into the Gunnison River below the Black Canyon would dampen or eliminate any control scheme implemented at the Aspinall Reservoirs. To evaluate this, we regressed water temperatures at Delta against temperatures in the Gunnison above the North Fork confluence (Figure 26). This data includes all daily average temperatures collected by FWS at these two sites during the months of June - October. Although some tributary inflows occur upstream of the "above North Fork" site, the significant tributary inflows of the North Fork of the Gunnison and the Uncompahgre occur between these two temperature monitoring sites. The regression shows a strong correlation between temperatures at the North Fork and at Delta, indicating that tributary inflows seem to have relatively little impact on stream temperatures through that reach.

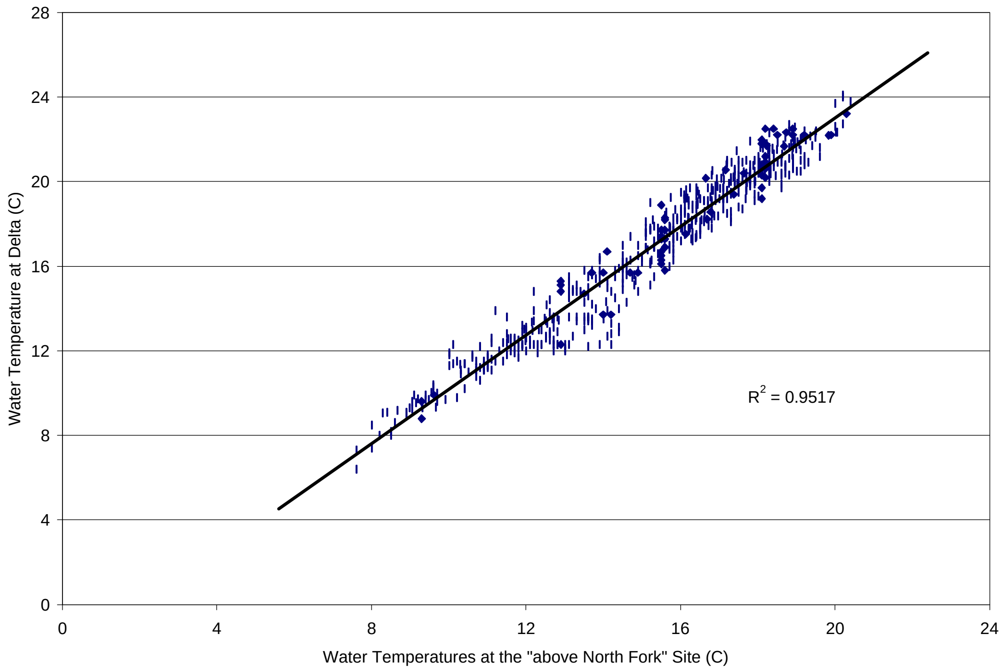


Figure 26. Average Daily Stream Temperatures at Delta as a Function of Average Daily Stream Temperatures above the North Fork, June - October.

5.3 Controllability of Temperatures at Delta

Given a basic understanding of the physical river system, our goal was then to determine whether or not warmer releases from the Aspinall Unit would result in warmer temperatures at Delta, and to what extent the magnitude of the flows below the Gunnison Tunnel regulated river heating. One of the complicating factors when analyzing water temperatures at Delta is the simultaneous influence of flow, release temperature, and atmospheric conditions on those temperatures. To determine the magnitude of the impact that release temperatures and flows have individually on water temperatures, we generated a simple MS Access database and extracted data for periods when two of the three variables had similar values. Air temperatures at the Delta NWS weather station were used as a surrogate for overall atmospheric conditions. The data were parsed according to the following criteria:

- Flows below the Gunnison tunnel in the ranges < 700 cfs, 700 - 1000 cfs, 1000 - 1300 cfs, 1300 - 1600 cfs, 1600 - 2000 cfs, and > 2000 cfs.

- Maximum daily air temperatures at Delta in the ranges 60 - 69 ^{o}F, 70 - 79 ^{o}F, 80 - 89 ^{o}F, > 90 ^{o}F.

- Crystal release temperatures in the ranges 7.0 - 7.9 ^{o}C, 8.0 - 8.9 ^{o}C, 9.0 - 9.9 ^{o}C, 10.0 - 10.9 ^{o}C, 11.0 - 11.9 ^{o}C, 12.0 - 12.9 ^{o}C (44.6 - 46.3 ^{o}F, 46.4 - 48.1 ^{o}F, 48.2 - 49.9 ^{o}F, 50.0 - 51.7 ^{o}F, 51.800 - 53.5 ^{o}F, 53.6 - 55.4 ^{o}F)

Data from the database were extracted in two ways. To test for the relationship between release temperature and water temperature at Delta, intersections of a given flow range and air temperature range were extracted. This provided us with a set of observations taken from periods when the only "moving" variable was release temperature. Similarly, to test impacts of flow below the Gunnison Tunnel on water temperature, we extracted data which had intersections of a given release temperature range and air temperature range.

5.4 Analysis of Release Temperature as a Temperature Control Option

Regression analyses on the data groupings extracted above indicate variable, yet consistently positive, relationships between Crystal release temperature and water temperature at Delta. Figures 27 through 29(a) show water temperatures at Delta as a function of release temperatures for combinations of atmospheric and flow conditions. These groupings were selected based on a combination of number of observations and range of release temperatures within the selected range. For example, other unused groupings had large sample sizes, but almost no variability in release temperature. The limited size of most samples resulted from a relatively small subset of dates for which all stations recorded values.

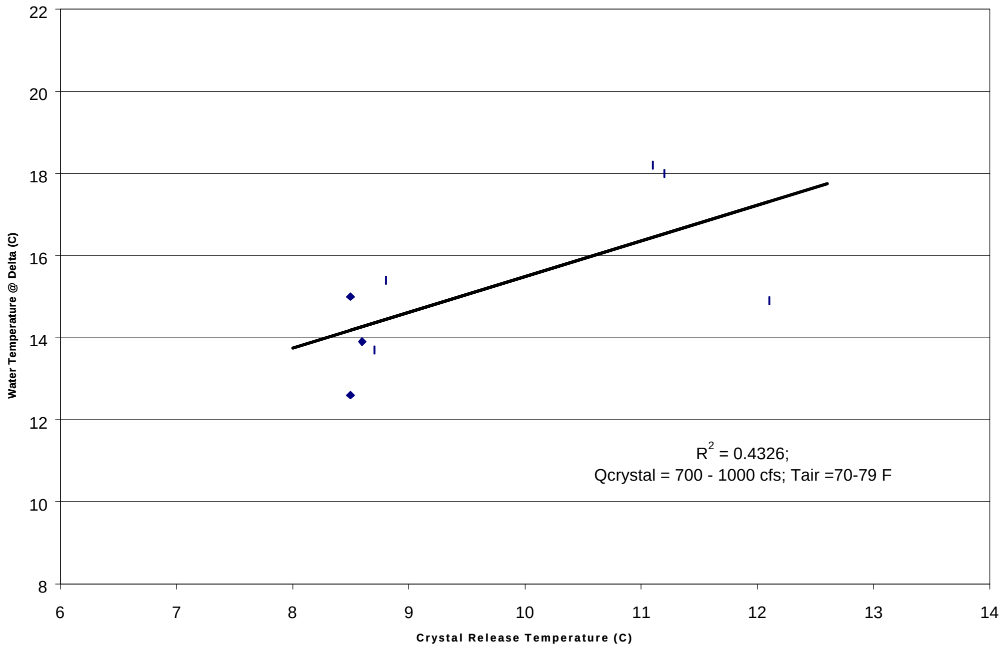


Figure 27. Gunnison River Temperatures at Delta as a Function of Crystal Release Temperature. Flows = 700 - 1000 cfs; Air Temperature = 70 - 79 °F.

In general, there is a consistent and significant positive correlation between release temperature and river temperature at Delta. Based on the slope of the regression equations, it appears that a 1 ^oC increase in release temperature generally results in about a 0.75 ^oC increase in Gunnison River temperatures at Delta.

Additionally, the results do not seem to be significantly impacted by tributary inflows. For example, all but two of the observations in Figure 27 are from June and early July of 1997, which was a fairly wet year in the Gunnison Basin (about 150% of average). In spite of this, there is a strong correlation between Crystal release temperatures and temperatures at Delta. This indicates that while large tributary inflows may cool the river, they do not contribute so much water to the system as to eliminate the effects of variable release temperatures from Crystal.

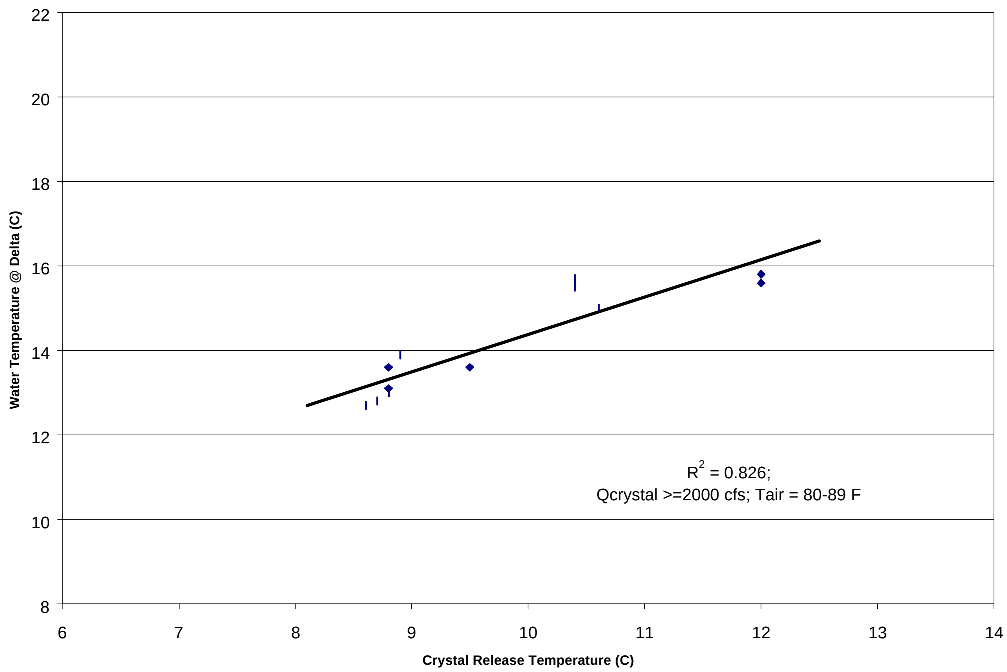


Figure 28. Gunnison River Temperatures at Delta as a Function of Crystal Release Temperature. Flows >= 2000 cfs; Air Temperature = 80 - 89 °F.

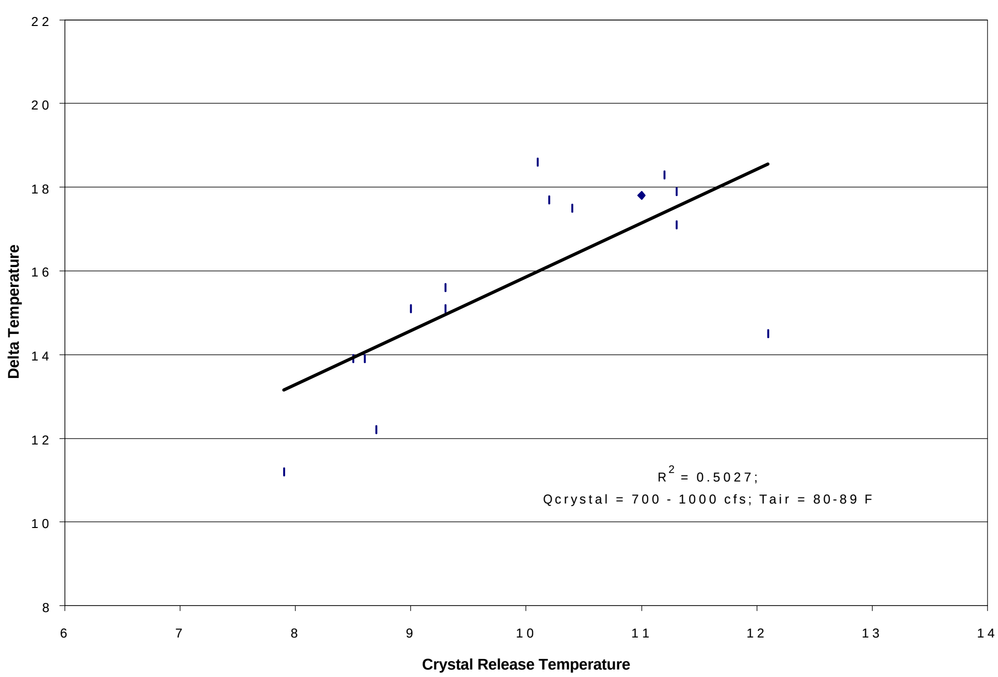


Figure 29(a). Gunnison River Temperatures at Delta as a Function of Crystal Release Temperature. Flows = 700 - 1000 cfs; Air Temperature = 80 - 89 °F.

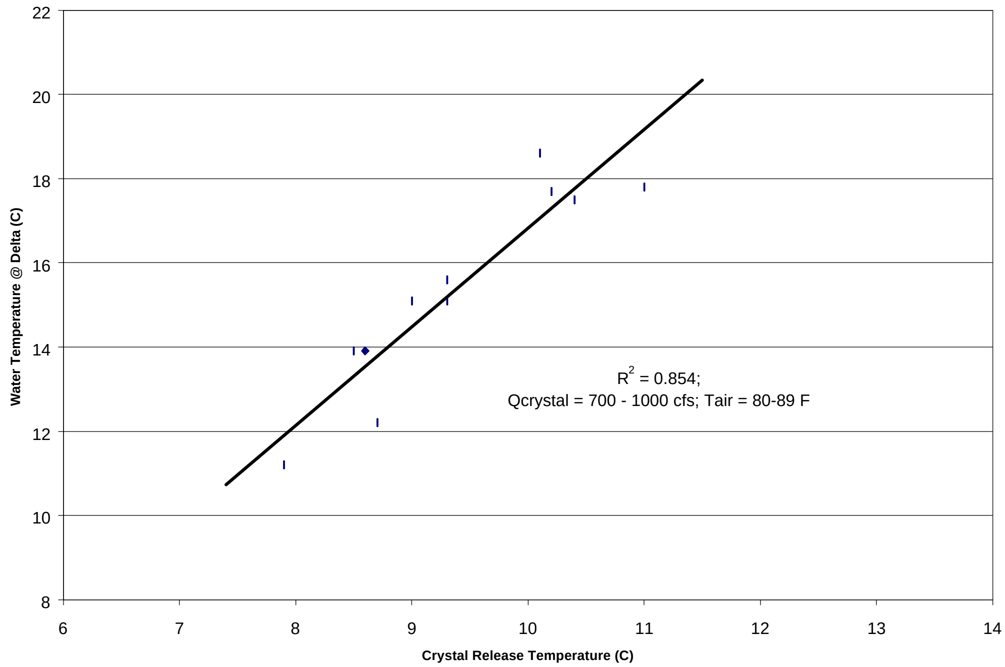


Figure 29(b). Gunnison River Temperatures at Delta as a Function of Crystal Release Temperature. This regression is a subset of 27a; Air temperature appears to be a poor surrogate for overall impacts of atmospheric conditions on river temperatures. Flows = 700 - 1000 cfs; Air Temperature = 80 - 89 °F.

Another observation we are able to make from these analyses is that air temperature seems to be a poor surrogate for overall atmospheric conditions. For example, Figure 29(b) is a subset of the data used in 29(a). It has been further parsed to include only those observations that occurred in June. There is a much stronger relationship between this parsed set of data. It appears that air temperature, in this system, does not accurately reflect the net atmospheric heating occurring at the air-water interface. It is likely that direct shortwave radiation, which will be limited by incidence angles, particularly in the canyon reaches of the river, isn't being reflected by air temperature. By further limiting the data to June observations, we arrive at a dataset which would have been subject to more similar radiative impacts. The resulting regression on Figure 29(b) shows the result, which is considerably more strongly correlated than 29(a).

5.5 Analysis of Flow-Based Control Options

A flow-based control option for managing temperatures at Delta would require significant restrictions to the timing and magnitude of release volumes passing below the Gunnison Tunnel. Such an approach would, however, not require any structural modifications to the Aspinall Unit. Figures 30 - 33 are examples of flow-to-temperature relationships at Delta. The first two charts show strong inverse correlation between flow and temperature, while the second two are quite poorly correlated.

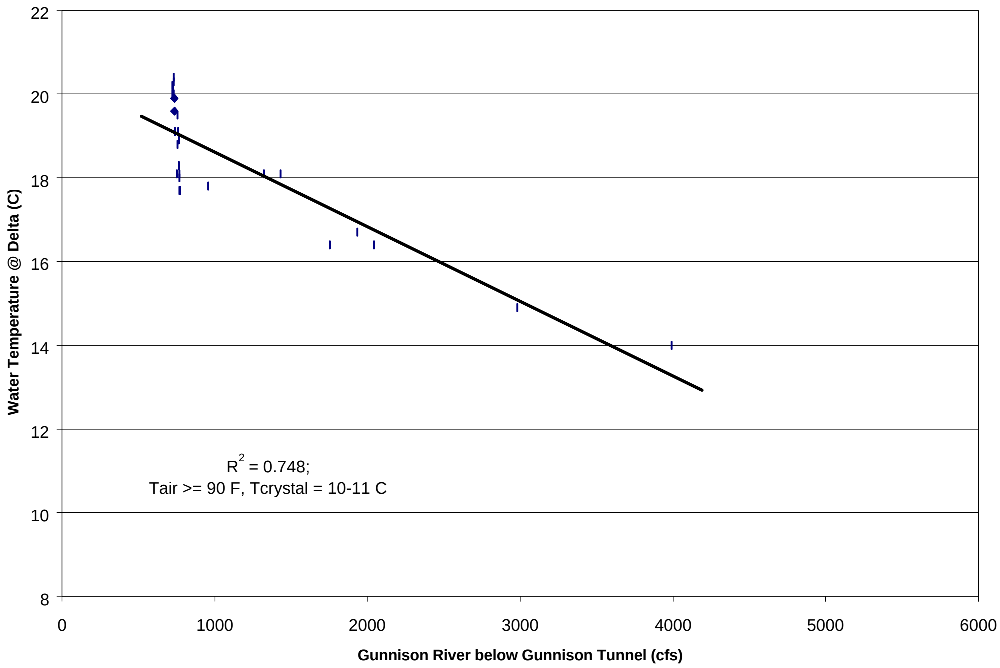


Figure 30. Gunnison River Temperatures at Delta as a Function of Flows below the Gunnison Tunnel. Release Temperature = 10 - 11 °C; Air Temperature >= 90 °F.

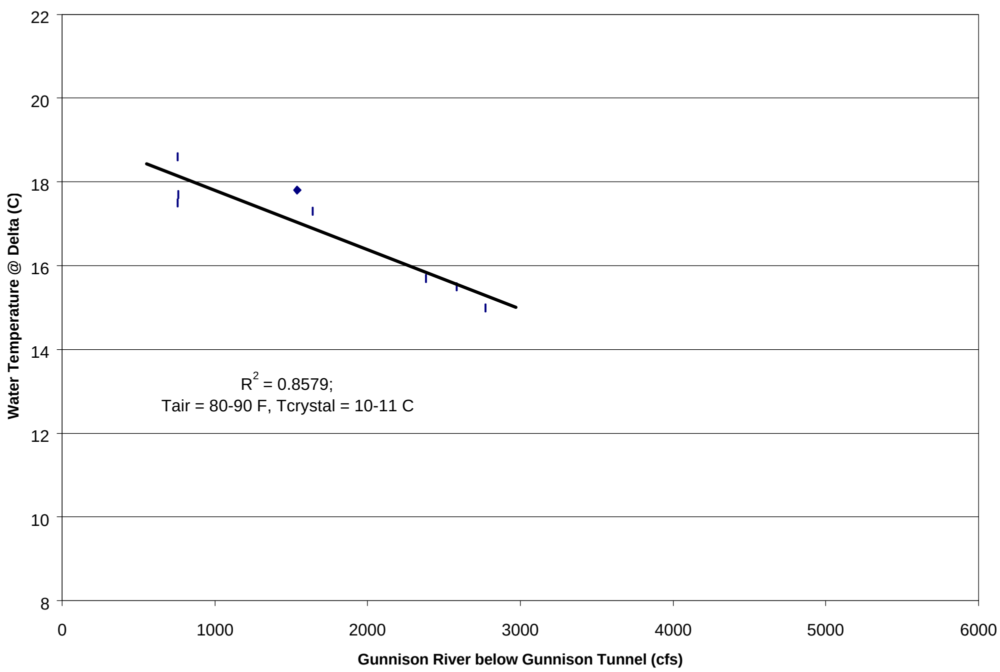


Figure 31. Gunnison River temperatures at Delta as a Function of Flows below the Gunnison Tunnel. Release Temperature = 10 - 11 °C; Air Temperature = 80 - 89 °F.

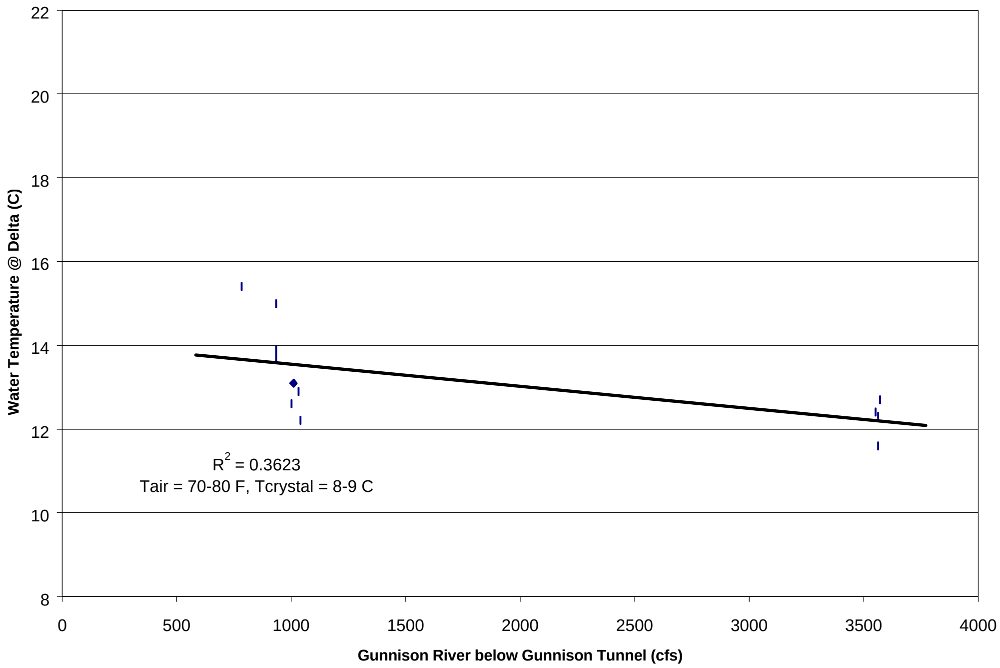


Figure 32. Gunnison River Temperatures at Delta as a Function of Flows below the Gunnison Tunnel. Release Temperature = 8 - 9 °C; Air Temperature = 70 - 79 °F.

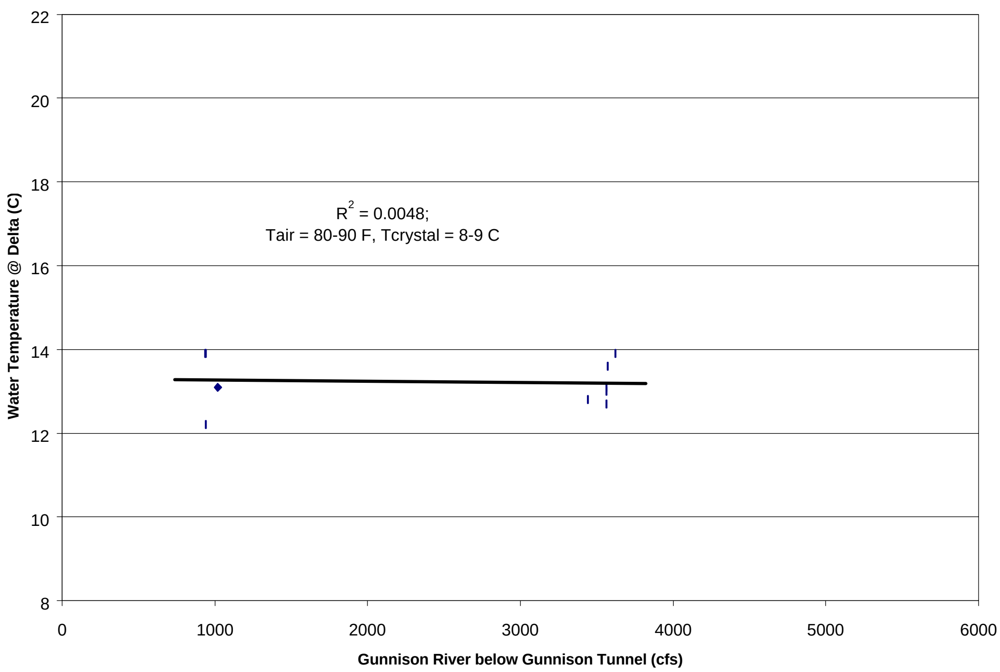


Figure 33. Gunnison River Temperatures at Delta as a Function of Flows below the Gunnison Tunnel. Release Temperature = 8 - 9 °C; Air Temperature = 80 - 89 °F.

Overall, the results indicate a great deal of variability in the degree of warming one might expect to achieve with a flow-based temperature control scheme. There may be several reasons for this. Unregulated tributary inflows during the peak of the snowmelt runoff are probably significant enough to make a flow-based control scheme ineffective. Additionally, air temperature appears to be a poor estimator of temperatures at Delta. In Figure 29, the cluster of observation points in the upper left of the graph are all from July 1998; they have nearly identical flows, and release temperatures within a degree of each other, yet temperatures at Delta vary by nearly 3 ^{o}C. It is likely that cloud cover (and hence reduced incident solar radiation), accounts for this variation.

From these data it appears that although release volume does have some impact on temperatures, those impacts are not of sufficient magnitude to be useful in meeting specific temperature targets.

5.6 Conclusions to River Temperature Analysis

Of the two potential control options, it appears that controlling release temperatures via a TCD would be the more effective method for warming river temperatures at Delta. Release temperatures appear to have a significant affect on resulting temperatures at Delta. Unlike a flow-based scheme, a TCD option does not rely on low flows persisting downstream to Delta, and thus would be less impacted by unregulated tributary flows. Flow-based schemes would suffer from greater impacts of tributary runoff, particularly during peak snowmelt runoff periods. Additionally, a flow-based scheme is likely to encounter a greater number of non-physical constraints which would limit its effectiveness.

6. OTHER CONSTRAINTS TO TEMPERATURE CONTROL

The primary objective of this project was to determine whether or not it is physically possible to control water temperatures near Delta. Regardless of the outcome of this phase and (possibly) phase II of the project with respect to the physical ability to increase temperatures, a whole host of additional institutional and physical constraints must be considered before any modifications, operational or structural, are implemented.

This section of the report attempts to address these other institutional constraints. These constraints include limitations in the existing physical, legal and operations structures that restrict the range of possible re-operations for temperature control. The constraints include both physical and institutional components, and these in turn could be classified based on how flexible the restrictions might be.

The constraints identified in this section are based on numerous conversations with persons at federal, state and local agencies and other interested groups, and on information gleaned from written reports and web-site content. For all of the constraints listed here, we provide a brief description, and some indication of whether or not the constraint would impact either the TCD or flow-based temperature control options.

6.1 Physical Constraints

Physical constraints include:

- Reservoir release capacity;
- Downstream flooding;
- Downstream diversion facilities;
- Landslide criteria at Crystal and Morrow Point reservoirs; and
- Entrainment potential.

6.1.1 Reservoir Release Capacity

Releases from Blue Mesa, Morrow Point and Crystal reservoirs can occur either through the outlet works or over the spillway. The outlet works can release water through turbines to generate electricity, or be bypassed directly to the river. The capacity of the power plant at Blue Mesa is between 2,600 and 3,400 cfs, and the capacity of the bypass is between 4,000 and 5,100 cfs, depending on the available head. Because of the shared nature of the outlet works, the total that can be released through the outlet works is 6,000 cfs. The gated spillway has a capacity of 34,000 cfs.

The outlet works at Morrow Point Reservoir has a capacity of 5,000 cfs through the power plant and 1,500 cfs through the bypass, for a total of 6,500 cfs. The gated spillway at Morrow Point has a capacity of 41,000 cfs. Physical release capacity at Crystal reservoir is 1,900 cfs through the power plant, up to 2,100 cfs through the bypass, for a total outlet works capacity of 4,000 cfs. The ungated spillway has a capacity of 41,350 cfs (Donald Phillips, USBR, personal communication, 2001).

Reservoir release capacity through the turbines determines a flow threshold above which water cannot be used for power production. The installed capacity is assumed to be a fixed constraint, so to maximize energy production and the use of a renewable resource, flow levels would need to be kept at or below the capacity of the turbines. These constraints are not likely to limit either temperature control option.

6.1.2 Downstream Flooding

Development in North Delta has occurred in the pre-dam flood plain. Grassy areas and portions of City Park are inundated at flows above 8,000 cfs, while homes and the town recreation center are impacted at flows above 10,400 cfs. Flows above 15,000 cfs cause operational problems for the Delta wastewater treatment plant (Jimmy Boyd, Wayne Scheidlt, State of Colorado, personal communication, 2001). It is unlikely that flood control issues at Delta would affect either temperature control option.

6.1.3 Downstream Diversion Facilities

The diversion dams on the Gunnison, which have been built post-dam construction, may not be designed to withstand the flow regimes proposed by the USFWS on an annual basis. While these dams withstood the high flows of 1995 and 1984, they may not be able to convey such flows on an annual basis without modification (Wayne Scheidlt, State of Colorado, personal communication, 2001). Neither of the potential temperature control options should impact these physical structures.

6.1.4 Landslide Criteria for Morrow Point and Crystal Reservoirs

For reservoirs with steep earthen banks, rapid reservoir drawdown, particularly during periods when the banks are saturated, can lead to bank failure. Landslides deposit material in the reservoir which reduces storage capacity, and leave unstable slopes, which are more prone to erosion and recurrent sliding in the future. Limits on the rate of draw-down have been put in place for Crystal Reservoir and are being evaluated for Morrow Point Reservoir to reduce the potential for landslides into the reservoirs, particularly during wet months. These constraints limit how rapidly the water surface can be lowered on a daily, 3-day and 5-day time frame (Brent Uilenberg, USBR, personal communication, 2001).

Limits on drawdown rates are considered a fixed constraint because there are no other practical ways to prevent landslides. This affects modeling, because peak flows in excess of the drawdown volumes must be generated through releases from Blue Mesa and not Morrow Point Reservoir. Given that the FWS proposed peak flows last from two to four weeks, the majority of water would have to come from Blue Mesa, meaning less operational flexibility for the operation of Morrow Point Reservoir.

It is unlikely that landslide criteria would impact either of the potential temperature control options.

6.1.5 Entrainment Potential

Entrainment is the introduction of foreign material into the intake to a hydroelectric generation or pumping unit. This is particularly important for multi-level intake structures, which can take water from the very top layer of the reservoir, where aquatic organisms and floating debris are most likely to be found. To reduce entrainment of floating matter, multi-level intakes are typically operated to take water from beneath the uppermost layer, which reduces the operational flexibility of the facility. These structures may also reduce the amount of head available for power generation.

Entrainment is one of the more significant potential limiting factors to use of TCDs. Depending on the hydraulic design of the TCD structure, withdrawals often must be made at depths of at least 8 to 15 meters (roughly 25 - 50 feet) below the water surface. This constraint can be particularly limiting during early summer months, when the epilimnion is thinnest, and the TCD may not be able to access warm waters near the top of the reservoir. Entrainment should not impact any flow-based temperature control options.

6.2 Non-Physical Constraints

Non-physical constraints include:

- Black Canyon of the Gunnison reserved water right;
- Water rights calls;
- Minimum stream flows;
- Recreational flows;
- Hydropower considerations;
- Blue Mesa winter operations;
- Recovery Program draft flow recommendations for endangered fish species;
- Riverine trout fisheries; and
- Reservoir fisheries.

6.2.1 Black Canyon of the Gunnison Reserved Water Right

The National Park Service has filed an application in Colorado Water Court for a federal reserved water right for the Black Canyon of the Gunnison National Park. The action taken is a quantification claim, as directed by the Water Court in a 1978 decree. In the 1978 decree, the Court said that the then-Monument was entitled to a federal reserved water right with a priority date of 1933, the date the monument was created, but did not decide the quantity of water for the right. Rather, the Court required the federal government to return to the Court later with a claim to quantify the right (NPS, 2001).

The application calls for the river to be operated to produce a more naturally shaped hydrograph, with higher peaks in the spring and lower flows the remainder of the year.

Because of the ongoing nature of the application, the actual impact of this claim is uncertain at this time.

Black Canyon reserved water rights are considered a fixed constraint, because while the amount of the water rights has not yet been decreed, it is almost certain that at least some water will be dedicated to that purpose. Minimum flows decreed by the state will have an adjudication date of 1933, the year the park was created, and so should be senior to the Colorado River Storage Project reservoirs on the Gunnison River. These water rights would have a direct impact on any flow-based temperature control approach. Flow-based temperature control could potentially require flows lower than the decreed instream flows.

6.2.2 Water Rights Calls

The two largest senior water rights on the Gunnison River are the Gunnison Tunnel, located below Crystal Reservoir, and the Redlands Irrigation Canal, located above the confluence of the Gunnison with the Colorado River. The Gunnison Tunnel has an absolute right for 1200 cfs, and the Redlands Canal has an absolute right for 750 cfs. In addition to these senior native rights, the Gunnison Tunnel has storage space in Taylor Park (and through an agreement with the USBR, Blue Mesa) that they can call water from when their native rights are insufficient to meet their demand (Jimmy Boyd, State of Colorado, personal communication, 2001).

There are four irrigation canals between Gunnison Tunnel and Redlands Canal. These ditches divert between 50 and 80 cfs, and could put a call on the river if operations are modified such that flows are lowered to the 300 cfs range.

Though many of the senior diverters below Crystal are far enough downstream not to call water out of Crystal, there is a potential that a call could affect a flow-based temperature control scheme.

6.2.3 Minimum Stream Flows

The Colorado Water Conservation Board holds a decree for a 300 cfs minimum flow on the Gunnison River from the Gunnison Tunnel diversion down to the confluence with the North Fork. The decree has an appropriation date of 12/10/1965 and is valid from January 1 through December 31 (CWCB, 2001). As with the Black Canyon reserved right, this water right would have a direct impact on any flow-based temperature control approach.

6.2.4 Recreational Flows

Recreation on the Gunnison includes fishing from the bank and boats, rafting and kayaking. River recreationists seem to prefer mid-level flows that are suitable for boating. The National Park Service advises the following flows in the park for kayaking, as measured below the Gunnison Tunnel (NPS-2, 2001):

750-950 cfs = minimal hydraulics

1200-1500 cfs = River is "pushy" with major hydraulics.

1500-3000 cfs = River is very "pushy" with extreme hydraulics.

above 3000 cfs = Kayaking should not be attempted even by experts, portages disappear, death is probable.

The Park Service also runs a flat water, motorized boat tour through the upper Black Canyon on Morrow Point Reservoir, within the Curecanti National Recreation Area, from Memorial Day through Labor Day. Changes in operations of Morrow Point Reservoir that would affect the operation of the tour during its operation season would likely draw objections from the Park Service. A flow-based control option would likely have some impact on these features. A TCD should not impact any of these recreational concerns.

6.2.5 Hydropower Considerations

The Western Area Power Authority generates power within mid- to long- term operational limits set by Reclamation. In wet years, power generation is typically run 24 hours a day at full capacity to convey water past the dams. In dry years, the system operates in a “maintenance” mode, where flows tend to be low and steady, with little room for seasonal shaping. Average runoff years tend to have the most room for shaping, with sufficient water to generate power and sufficient space to allow for modification of the hydrograph (Mark Wieringa, WAPA, personal communication, 2001).

Power generated from the hydroelectric plants on the Gunnison River is used to provide peaking power, with Crystal acting as a re-regulation reservoir. Under ideal operations, water would be used to meet morning and evening peaks in the summer and winter months. WAPA is committed to deliver a set amount of power, but is not tied to delivering it from a particular plant at any certain time.

All other things being equal, WAPA prefers to make releases seasonally so the maximum flow out of Crystal is 2000 cfs, the capacity of the generators. This is done by forecasting how much water will run off each spring and releasing water from storage in late winter to create sufficient space to hold the spring runoff. Operating in this manner eliminates spill from the reservoirs, maximizing the amount of power generated.

Both flow-based and TCD options for temperature control would impact power production from the Aspinall Unit. Of the two, a TCD approach would minimize this impact. Nevertheless, some loss of generation would be incurred due to hydraulic properties of TCDs.

6.2.6 Blue Mesa Winter Operations

To prevent icing problems at the upstream end of Blue Mesa Reservoir during the winter, current reservoir operations call for the reservoir to be drawn down below specified levels before January 1 (Brent Uilenberg, USBR, personal communication, 2001). Winter operations probably would not impact either temperature control options.

6.2.7 Recovery Program Draft Flow Recommendations for Endangered Fish Species

The U.S. Fish and Wildlife Service has proposed that operations be modified to produce a peak flow of at least 4000 cfs below Crystal between May 15 and June 15, with releases made to match the peak flows from the North Fork. These flows are desirable to create flushing flows, which cause bed movement, providing fresh gravel beds for spawning habitat (McAda, personal communication, and Draft flow Recommendations).

The flow recommendations would clearly impact any flow-based temperature control options. Temperature control with a TCD should not be affected by these flow recommendations.

6.2.8 Riverine Trout Fisheries

The Gunnison River from Crystal Dam to the North Fork confluence is designated Gold Medal Water by the Colorado State Wildlife Commission. According to Dave Nickum of Trout Unlimited, a significant trout fishery extends downstream from the confluence to the vicinity of the Hartland Diversion Dam.

It is likely that the downstream extent of the fishery is limited by warm water temperatures, particularly in late summer when flows are typically low. Any increase in Crystal release temperatures would result in a warming of water temperatures downstream, and may act to reduce the number of river miles considered good trout habitat. It is worth noting that current temperatures in the Gold Medal section of the Gunnison below Crystal are actually lower than those identified as "optimal" temperatures for trout growth (Dave Nickum, TU, personal communication, 2001)

Another issue to consider with respect to the trout fishery is that of whirling disease. Optimal temperatures for the whirling disease parasite are around 14 ^{o}C (Dave Nickum, TU, personal communication, 2001). Modification of Crystal release temperatures could either positively or negatively impact control of whirling disease.

6.2.9 Reservoir Fisheries

Reservoir fisheries data and information was obtained from several written reports (Annual Progress Reports) by Brett Johnson (Johnson et al, 1997, 1998, 1999). Johnson has expressed concern that changes in reservoir operations could have detrimental affects on the reservoir fishery. Johnson notes that he "evaluated thermal effects and discovered that if the reservoir was drawn down enough in summer that epilimnetic water was released it could have consequences for predator-prey interactions among lake trout and kokanee, but only if unrealistically high releases occurred in a dry year. Our most recent modeling using more realistic operations scenarios provided by USBR and USFWS suggest that thermal consequences of a new release pattern (not new release depths) are almost negligible compared to the effects of climate and hydrology (Johnson et al. in prep). I would, however, be more concerned about possible effects of a shallower withdrawal depth since that could conceivably have a thermal effect on the reservoir, and may also present an entrainment issue for zooplankton and kokanee (Brett Johnson, CSU, personal communication, 2002).

Mark Weiringa of WAPA noted that installing a multi-level intake could cause detrimental effects in the reservoir due to depleted oxygen levels in the reservoir (Mark Wieringa, WAPA, personal communication, 2001).

Both flow-based and TCD based options could impact reservoir fisheries. Of particular concern would be impacts of a TCD on the thermal structure of the reservoir, which in turn directly impacts other water quality parameters such as dissolved oxygen. Dissolved oxygen may cause separation of species within the reservoir, and anomalous DO reading have at times been observed in parts of Blue Mesa reservoir (Brett Johnson, CSU, personal communication, 2002).

6.3 Implications of Constraints on Temperature Controls

We considered both TCD and flow-based options for temperature control below Crystal dam when compiling the constraint list. Of the two potential options, a flow-based temperature control scheme is likely to encounter more limitations than a TCD option would. The Recovery Program flow recommendations, senior and reserved water rights, flood control issues, and reservoir and river recreational issues are all probable limiting factors to such an approach.

A TCD approach, while less constrained, still would need to be evaluated against its impacts on several system components including reservoir fisheries, entrainment concerns, and hydropower generation. An in-depth analysis of all of these constraints and how they may be impacted would help clarify the net value of the temperature control options.

7. CONCLUSIONS AND RECOMMENDATIONS

The goals of this study were to 1) collect and inventory data relative to analyzing and modeling water temperatures in the Gunnison Basin, 2) examine potential physical and institutional constraints to achieving warmer stream temperatures near Delta, 3) conduct a preliminary analysis of the data to determine the potential effectiveness of managing the Aspinall Unit reservoirs for downstream temperature control, and 4) make recommendations for future modeling and data collection efforts.

The preliminary results of the reservoir and river data analyses seem to indicate that a temperature control device, most likely located at Blue Mesa Dam, could be used to achieve warmer temperatures in the Gunnison River near Delta. We strongly recommend a rigorous modeling study be conducted on the three Aspinall Unit reservoirs to better understand the implications of a TCD on one or more of the structures. Additionally, we recommend a river temperature modeling exercise, based either on QUAL-2E or on a multivariate statistical model. Our preliminary results indicate that since longer-term average temperatures in the river are more relevant than daily or hourly temperatures, a rigorous mechanistic model of the river system may be unnecessary.

8. REFERENCES AND SELECTED BIBLIOGRAPHY

Analysis and Model data sources are highlighted with an asterisk (*).

Boyd, Jimmy. 2001. State of Colorado, District 40 Water Commissioner. Personal communication.

*Butler, D.L. 2000. Evaluation of Water-Quality Data, Lower Gunnison River Basin and Colorado River Downstream from the Aspinall Unit, Colorado. U.S. Geological Survey Administrative Report.

Burdick, B.D. 1995. Ichthyofaunal studies of the Gunnison River, Colorado, 1992-1994. Final Report. Colorado River Fishery Project (USFWS). Grand Junction, Colorado.

Carron, J.C. 2000. Simulation and Optimization of Unsteady Flows and Stream temperatures in Reservoir-Regulated Rivers. Ph.D. Thesis, Department of Civil, Environmental, and Architectural Engineering, University of Colorado, Boulder.

Carron, J.C. and H. Rajaram. 2001. Impact of variable reservoir releases on management of downstream water temperatures. Water Resources Research, V37 N6, 1733-1743.

Colorado Water Conservation Board web site: "Gunnison River 4-92CW107" http://cwcb.state.co.us/isf/Database/detail.asp?seg=4%2D92CW107&stream_name=Gunnison+River. Sep 10, 2001.

*Hydrosphere Data Products. 2000. HYDRODATA 2000 (volume 12.0, West 1 USGS Daily Values).

*Hydrosphere Data Products. 2000. CLIMATEDATA 2000 (volume 11.0, West 1 NCDC Summary of the Day).

Johnson, B. M., J. D. Stockwell, K. Bonfantina. 1997. Ecological Effects of Reservoir Operations on Blue Mesa Reservoir. Annual Progress Report, May 1 1996-April 30 1997. Colorado State University.

Johnson, B. M. and J. D. Stockwell. 1998. Ecological Effects of Reservoir Operations on Blue Mesa Reservoir. Annual Progress Report, May 1 1997-April 30 1998. Colorado State University.

Johnson, B. M., M Koski, and M Anderson. 1999. Refine Modeling Tools to Forecast Effects of Dam Operations on Reservoir Food Webs. Annual Progress Report, May 1 1998-April 30 1999." Colorado State University.

Long, B.A., L.S. Cudlip, and R.A. Smith. 1995. Water Quality Data Analysis and Interpretation: Curecanti National Recreation Area. U.S. Department of the Interior.

Malick, Matt. 2001. Curecanti National Recreation Area. Personal communication.

*Malick, Matt. 2001. National Park Service database of water quality and quantity records. Curecanti National Recreation Area.

McAda, Chuck. 2001 .USFWS, Grand Junction. Personal communication.

National Park Service. 1996. Water Resources Management Plan. Curecanti National Recreation Area. U.S. Department of the Interior.

*National Park Service. 1998. Baseline Water Quality Data Inventory and Analysis: Curecanti National Recreation Area. Volumes I and II. Department of the Interior, Washington, D.C.

National Park Service web site: "Live! Claim Filed for Water Rights, Updated Friday, September 7, 2001." http://www.nps.gov/blca/webvc/live!.htm.

National Park Service - 2 web site: "Black Canyon of the Gunnison, Kayaking," http://www.nps.gov/blca/webvc/kayak.htm.

Osmundson, D.B. 1999. Longitudinal Variation in Fish Community Structure and Water Temperature in the Upper Colorado River. Final Report, Recovery Action Plan, Project # 48-A. U.S. Fish and Wildlife Service.

Osmundson, D.B. 2001. USFWS. Personal communication.

Phillips, Donald. 2001. Manager, Curecanti Field Division, USBR. Personal communication.

Quarterone, F. 1993. Historical Accounts of Upper Colorado River Basin Endangered Fish. Final Report. Colorado Division of Wildlife, Denver.

Schieldt, Wayne. 2001. State of Colorado Division Engineer, Division 4. Personal communication.

Sinokrot, B.A., and H.G. Stefan. 1993. Stream Temperature Dynamics: Measurement and Modeling. Water Resources Research, 29(7), 2299-2312.

Smith, George. 2000. U.S. Fish and Wildlife Service. Personal communication.

*Smith, George. 2000. Raw Hourly and Daily Mean Water Temperatures in the Gunnison River Basin. U.S. Fish and Wildlife Service.

Stanford, J.A. 1994. Instream Flows to Assist the Recovery of Endangered Fishes of the Upper Colorado River Basin. Biological Report 24. National Biological Survey, U.S. Department of the Interior.

Uilenberg, Brent. 2001. U.S. Bureau of Reclamation. Personal communication.

Uilenberg, Brent, et al. 2001. Phone conference with Brent Uilenberg, Steve McCall, Ed Werner, Dan Crabtree, and Coll Stanton. Sep 7, 2001.

Valdez, R.A., P.G. Mangan, R.P. Smith, and B.C. Nelson. 1982. Upper Colorado River Investigation (Rifle, Colorado to Lake Powell, Utah). Colorado River Fishery Project, Part 2; pp 100-279. Salt Lake City, Utah.

Wieringa, Mark. 2001. Western Area Power Authority, Office of Environment. Personal communication.

Wetzel, R.G., 1983. Limnology. Saunders College Publishing, 2nd Edition.

APPENDIX

This appendix provides summary tables of available data for the more significant data sources used in this work.

Table A-1: Selected Hydrologic (flow) Stations Periods of Record

StationID	Station Name	Start Yr	End Year	Num Years	Num Obs
09114000	OHIO CREEK NEAR GUNNISON, CO.	1944	1950	7	2191
09114500	GUNNISON RIVER NEAR GUNNISON, CO.	1910	1998	74	26298
09114500	GUNNISON RIVER NEAR GUNNISON, CO.	1990	1991	2	149
09119000	TOMICHI CREEK AT GUNNISON, CO.	1937	1998	62	22280
09120500	GUNNISON RIVER AT IOLA, CO.	1938	1951	14	4931
09123000	SOAP CREEK AT SAPINERO, CO.	1910	1952	13	4018
09124700	GUNNISON RIVER BELOW BLUE MESA DAM, CO.	1963	1968	6	1888
09126500	CIMARRON RIVER AT CIMARRON, CO.	1902	1967	10	3166
09127000	CIMARRON RIVER BL SQUAW CREEK, NR CIMARRON, CO.	1942	1952	11	3653
09127998	GUNNISON RIVER ABOVE GUNNISON TUNNEL, CO.	1905	1965	61	22048
09127999	GUNNISON TUNNEL NEAR MONTROSE, CO.	1915	1965	51	18263
09128000	GUNNISON RIVER BELOW GUNNISON TUNNEL, CO.	1910	1998	89	32142
09135950	N.F. GUNNISON R BLW LEROUX CR, NR HOTCHKISS, CO	1997	1998	2	215
09136200	GUNNISON RIVER NEAR LAZEAR, CO.	1962	1985	24	8554
09144250	GUNNISON RIVER AT DELTA, CO.	1976	1998	23	8157
09144250	GUNNISON RIVER AT DELTA, CO.	1990	1991	2	141
09149500	UNCOMPAHGRE RIVER AT DELTA, CO.	1938	1998	61	21915
09149500	UNCOMPAHGRE RIVER AT DELTA, CO.	1959	1959	1	8
09150500	ROUBIDEAU CREEK AT MOUTH, NEAR DELTA, CO.	1938	1983	25	8564
09151500	ESCALANTE CREEK NEAR DELTA, CO.	1976	1989	14	4901
09152500	GUNNISON RIVER NEAR GRAND JUNCTION, CO.	1896	1998	93	32871
09152500	GUNNISON RIVER NEAR GRAND JUNCTION, CO.	1959	1959	1	14
09152500	GUNNISON RIVER NEAR GRAND JUNCTION, CO.	1990	1991	2	166

Source: HYDRODATA 2000 (volume 12.0, West 1 USGS Daily Values)

Table A-2: Selected Climate Stations Periods of Record and Count of Years for Selected Parameters

StationID	Station Name	Start Year	End Year	Count of Years: AIR TEMP	EVAP TOT	PRECIP TOT	SNOW DEPTH	Wind dir /spd & Dew Pt
1440	CEDAREDGE	1948	1994	47		47	47	
1443	CEDAREDGE 3 E	1996	1999	4		4	4	
1609	CIMARRON	1951	1999	49		49	49	
2192	DELTA	1900	1999	99		99	98	
3662	GUNNISON 3 SW	1900	1999	100		100	100	
5717	MONTROSE 1	1948	1982	1	35	35	35	
5722	MONTROSE NO 2	1900	1999	97		100	100	
6081	OLATHE	1948	1955			8	8	
6116	OLATHE 4 SSW	1983	1985		3	3	3	
7455	SAPINERO 8 E	1948	1965	2		8	8	
794	BLUE MESA DAM	1966	1967			2	2	
797	BLUE MESA LAKE	1967	1999	18		33	33	
	GUNNISON CO (AWOS)	1946	2001	Data not in Climatedata				*
8184	TAYLOR PARK	1948	2001	52		52	52	*
3488	GRAND JUNCTION	1900	2001	100	13	100	100	*
	MONTROSE CO. ARPT	1947	2001	Data not in Climatedata				*

Source: CLIMATEDATA 2000 (volume 11.0, West 1 NCDC Summary of the Day)

Table A-3: NPS Database Summary: Reservoir Profile Stations Periods of Record and Count of Years for Available Parameters

StationID	Station Name	Start Year	End Year	Count of Years: DEPTH	WATER TEMP	pH	DIS OXY	COND
CEBO	Blue Mesa Cebolla Basin	1994	2000	965	965	965	965	938
CRYS1	Crystal Reservoir at Crystal Dam	1998	2000	395	395	395	395	395
CRYS2	Crystal Reservoir at Crystal Creek	1994	2000	270	270	270	270	270
IOLA	Blue Mesa Iola Basin	1994	2000	662	662	662	662	662
MOR1	Morrow Point at Hermits Rest	1994	2000	908	908	908	879	908
MOR2	Morrow Point at Kokanee Bay	1997	2000	629	629	629	608	629
SAPI	Blue Mesa Sapinero Basin	1994	2000	1058	1058	1058	1058	1058

Table A-4: NPS Database Summary: Reservoir Elevation Stations Periods of Record and Count of Years for Available Parameters

			Count of Years			
Station Name	Start Year	End Year	ELEV-ATION	CONT-ENTS	IN-FLOW	DIS-CHARGE
Blue Mesa Reservoir	1967	2001	12567	12567	12567	12567
Crystal Reservoir	1977	2001	8841	8841	8841	8841
Morrow Point Reservoir	1970	2001	11137	11137	11137	11136

Table A-5: NPS Database Summary: Temperature and Flow Stations Periods of Record and Count of Years for Available Parameters

				Count of Years	
StationID	Station Name	Start Year	End Year	WATER TEMP	FLOW
BC01	Blue Creek	1982	2000	75	33
BM01	Lake Fork Arm: BML04 from Don Hickman Thesis	1982	2000	122	0
BM02	Lake Fork Marina: BML02 from Don Hickman Thesis	1982	1992	73	0
BM03	Haystack Gulch	1984	2000	106	1
BM04	Sunnyside	1983	2000	108	1
BM05	Iola: BML42 from Don Hickman Thesis	1983	2000	125	0
BM13	McIntyre Gulch	1988	1992	36	0
BM18	BMH Site: BML13 from Don Hickman Thesis	1982	2000	101	0
BM19	Elk Creek Marina: BML31 from Don Hickman Thesis	1975	2000	101	2
BM20	South Bay Near Middle Bridge	1984	2000	13	3
BML01	DAM: SAPINERO BASIN	1975	1985	36	0
BML03	LAKE FORK ARM: BRIDGE	1983	1985	16	0
BML05	LAKE FORK ARM: WILLOW CREEK	1983	1985	16	0
BML06	LAKE FORK ARM: MIDDLE	1982	1985	28	0
BML07	LAKE FORK ARM: SOUTH	1984	1985	6	0
BML08	SAPINERO: SAPINERO BASIN	1974	1985	24	0
BML09	MCINTYRE GULCH: SAPINERO BASIN	1982	1985	31	0
BML10	SOAP ARM: SOUTH	1982	1985	41	0
BML11	SOAP ARM: MIDDLE	1982	1985	31	0
BML12	SOAP ARM: NORTH	1984	1985	16	0
BML14	WEST ELK ARM: SOUTH	1982	1985	42	0
BML15	WEST ELK ARM: MIDDLE	1982	1985	30	0
BML16	WEST ELK ARM: NORTH	1984	1985	13	0
BML17	DILLON PINNACLES: SAPINERO BASIN	1983	1985	11	0
BML18	LAKE CITY CUTOFF: SAPINERO BASIN	1983	1985	18	0
BML19	MIDDLE BRIDGE: SAPINERO BASIN	1982	1985	31	0
BML20	RED CREEK ISLAND: CEBOLLA BASIN	1983	1985	12	0
BML21	RED CREEK SLIDE: CEBOLLA BASIN	1975	1985	36	0
BML22	CEBOLLA ARM: NORTH	1982	1985	33	0
BML23	CEBOLLA ARM: SKI BEACH	1983	1985	18	0
BML24	CEBOLLA ARM: LAKE BEND	1982	1985	31	0
BML25	CEBOLLA ARM: SOUTH	1984	1985	8	0

BML26	DEEP CREEK: CEBOLLA BASIN	1983	1985	14	0
BML27	DRY GULCH: CEBOLLA BASIN	1982	1985	31	0
BML28	BAY OF CHICKENS: CEBOLLA BASIN	1983	1985	27	0
BML29	BAY OF CHICKENS BEACH: CEBOLLA BASIN	1984	1985	28	0
BML30	THE NARROWS	1983	1985	25	0
BML32	DIVERS ROCK	1983	1985	10	0
BML33	DRY CREEK	1983	1985	36	0
BML34	KEZAR GULCH I	1982	1985	10	0
BML35	KEZAR GULCH II	1982	1985	30	0
BML36	BIG GAME HILL: IOLA BASIN	1982	1985	10	0
BML37	WILLOW CREEK ISLAND-WEST: IOLA BASIN	1975	1985	34	0
BML38	WILLOW CREEK ISLAND-EAST: IOLA BASIN	1975	1985	18	0
BML39	STEVENS CREEK GULCH: IOLA BASIN	1983	1985	18	0
BML40	STEVENS CHANNEL: IOLA BASIN	1983	1985	21	0
BML41	IOLA CHANNEL: IOLA BASIN	1983	1985	17	0
BML43	SOUTH WILLOW CREEK: IOLA BASIN	1982	1985	17	0
BML44	SOUTH WILLOW CREEK CHANNEL: IOLA BASIN	1982	1985	28	0
BML45	MAIN GULCH CHANNEL: IOLA BASIN	1983	1985	14	0
BML46	MAIN GULCH: IOLA BASIN	1975	1985	17	0
BML47	LAKE CITY BRIDGE: IOLA BASIN	1975	1985	30	0
BML48	WILSON'S LANDING	1982	1985	19	0
CB1A	Cebolla Creek	1984	2000	108	49
CEB1	CEBOLLA CREEK - BLUE MESA LAKE	1982	1983	14	0
CIM1	CIMARRON CREEK - CONFLUENCE WITH GUNNISON	1982	1985	20	9
CIM2	CIMARRON CREEK - EAST CIMARRON	1981	1985	19	9
CL01	CRYSTAL LAKE - DAM	1982	1985	18	0
CL02	CRYSTAL LAKE - WEST OF CRYSTAL CREEK	1982	1985	19	0
CL03	CRYSTAL LAKE - LONG GULCH	1982	1985	18	0
CL04	Crystal Res Below Mesa Creek	1982	2000	59	0
CM08	Cimarron above Squaw	1987	1992	39	0
CM10	Cimarron below Squaw	1987	2000	138	65
CM12	Cimarron above Bennys	1987	1992	37	0
COR1	CORRAL CREEK - HWY 92	1982	1999	44	4
CUR1	CURECANTI CREEK - HWY 92	1982	1985	31	0
CUR2	Curecanti Creek	1983	2000	86	36
CYC1	Crystal Creek	1982	1999	22	4
DG1	DRY GULCH - CAMPGROUND	1982	1985	27	0
EEC1	EAST ELK CREEK - CAMPGROUND	1982	1999	44	4
GR01	Gunnison R - Black Canyon	1982	2000	75	47
GR02	GUNNISON RIVER - BELOW MORROW POINT DAM	1982	1985	25	20
GR03	GUNNISON RIVER - BELOW BLUE MESA DAM	1981	1992	47	30
GR04	GUNNISON RIVER - COOPER RANCH	1981	1985	66	38
GR05	GUNNISON RIVER - NEVERSINK	1981	1985	64	45
GR07	Gunnison R - Riverway	1981	2000	151	79
GR08	Gunnison R - Red Rock Canyon	1995	2000	39	33
GR4A	Gunnison R - Cooper Ranch	1993	1994	16	0
LF01	Lake Fork	1981	2000	141	82

MC1	MESA CREEK - CRYSTAL LAKE	1982	1999	14	3
MPL1	MORROW POINT LAKE - DAM	1982	1985	20	0
MPL2	MORROW POINT LAKE - WEST OF ROUND CORRAL	1982	1985	18	0
MPL3	MORROW POINT LAKE - WEST OF MEYERS GULCH	1982	1985	20	0
MPL4	MORROW POINT LAKE - BLUE CREEK	1982	1985	17	0
MPL5	MORROW POINT LAKE - WEST OF HAYPRESS CREEK	1982	1985	15	0
MPL6	Morrow Pt Res Below Pine Creek	1982	2000	62	1
NBC1	NORTH BEAVER CREEK - PICNIC AREA	1982	1999	48	4
NW06	Lower North Willow	1987	1992	30	0
NW11	Upper North Willow	1987	1992	39	0
NWC1	NORTH WILLOW CREEK - HWY 50	1982	1985	41	0
PC01	Pine Creek	1982	2000	139	52
RC1	RED CREEK	1982	1999	45	4
RRC1	Red Rock Canyon	1996	2000	40	32
SBC1	SOUTH BEAVER CREEK - GUNNISON RIVER	1982	1985	12	0
SC01	Steubon Creek Access Road	1982	2000	130	46
SC09	Squaw above Cimarron	1987	1992	38	0
SOAP	SOAP CREEK - PONDEROSA CAMPGROUND	1982	2000	22	5
SWC1	SOUTH WILLOW CREEK - ACCESS ROAD	1982	1999	19	1
WEC1	West Elk Creek	1982	2000	82	35

Table A-6: FWS Database Summary: Gunnison River Temperature Recorders.

Station Name	Period(s) of Record
Gunnison River below Crystal Dam	1996-2001
Gunnison River above the North Fork	1996-1998, 2000-2001
Gunnison River near Delta	1992, 1995-2001
Gunnison River near Grand Junction	1992-1995, 1997-1998, 2000-2001